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

A Thesis Presented

by

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ABSTRACT

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MAY 2011

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Arguably the greatest issue facing the transportation profession is the ability to provide social equity with regards to both safety and mobility given the aging population. Given the overall 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 spatial crash analysis and road safety investigations that were employed in Massachusetts with a direct 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 both intersections and roadway segments 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 Design Handbook, included a full spectrum of recommendations, a specific emphasis was placed upon 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.

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LIST OF ABBREVIATIONS

UMassSAFE	University of Massachusetts Traffic Safety Research Program
NHTSA	National Highway Traffic Safety Administration
FHWA	Federal Highway Administration
GHSB	Governor's Highway Safety Bureau
EOPSS	Executive Office of Public Safety & Security
RSA	Road Safety Audit
RSI	Road Safety Investigation
MassDOT	Massachusetts Department of Transportation
EPDO	Equivalent Property-Damage-Only
HCL	High Crash Location
ODHCL	Older Driver High Crash Location

1.0 INTRODUCTION

One of the most critical challenges facing the transportation profession, and society as a whole, is social equity associated with the ability of people to travel. The continued maintenance of a safe and efficient transportation system has far reaching implications including increased economy 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 shopping at the local grocery store become challenging. 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. An 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 (1). The population is not only growing but is expected to become much older. It is estimated 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 (2). These trends will be seen in every state, including the Commonwealth of Massachusetts, as shown in Figure 1. 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 (3).

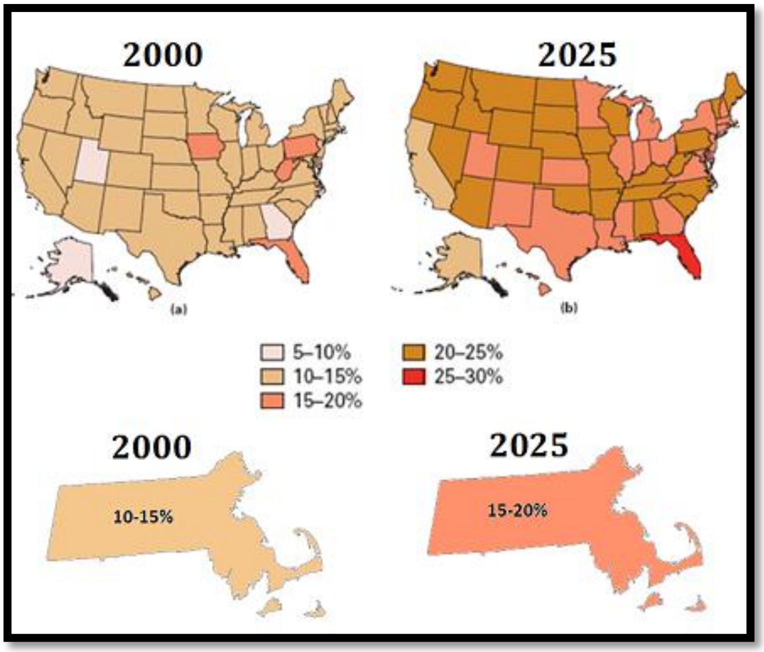


Figure 1. Percentage of Population 65 Years of Age or Older (2)

Not only is the population growing and aging, but people are driving much later in life. Nationally, the proportion of the driving population 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 (4). 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 (5).

The associated impacts of these figures are serious as they relate to the safety and well-being of the public. Although it might improve overall road safety, if seniors are forced to surrender their licenses, they lose the mobility and freedom they have enjoyed their entire life, and negative health outcomes are the consequence. Yet, the overall roadway network is compromised as crash rates may increase if older drivers attempt to stay on the road when perhaps they ought to hang up their keys for good. 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 (6). 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 (6). Looking at fatalities per mile traveled, older drivers have a greater fatality rate than other adult drivers (7).

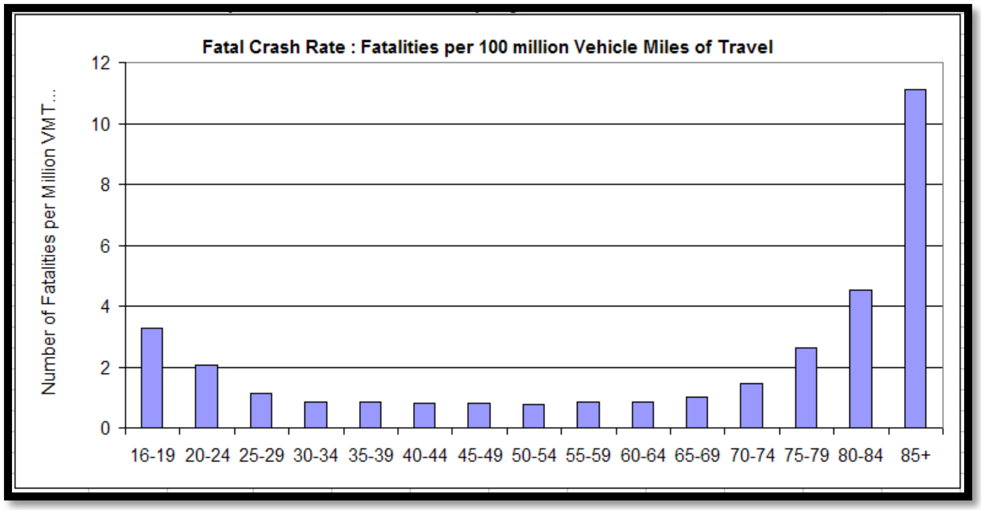


Figure 2. Fatalities per 100 Million Vehicle Miles Traveled by Driver Age, 2007 (7)

These figures indicate that the safety of older drivers is becoming an issue of national importance and it is the responsibility of transportation professionals around the country to ensure that older citizens remain mobile and independent while maintaining road safety. This poses a challenge while the private automobile remains the preferred mode of transportation; 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. Measures which 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. It is crucial to society as a whole that older drivers are safely able to operate a motor vehicle for as long as possible.

Problem Statement

Arguably the greatest issue facing the transportation profession is the ability to provide social equity with regards to both safety and mobility given the aging population. Given the overall 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 that focus upon the older driver.

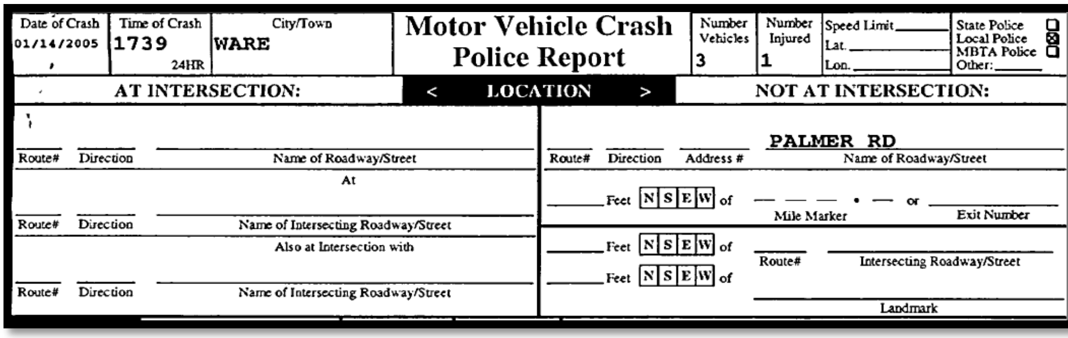
Research Objective

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 identification methodologies and analytic spatial techniques to develop novel methods of identifying locations where older drivers are overrepresented in crashes. The specific aim was to develop methodologies to identify those intersections and roadway segments 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, focusing exclusively on the older driver. More specifically, the aim was to use the developed approaches for identifying high crash locations for older drivers by subsequently conducting older-driver themed road safety investigations. The road safety investigations 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 Design Handbook, include a full spectrum of recommendations, a specific emphasis was placed upon short-term and low cost measures that could be readily employed. This clearly identifies the specific circumstances in which 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. Next, an evaluation of the crash reductions for the selected countermeasures (low, moderate, or high), estimate the timeframe for implementation (short, medium, or long), and predict the relative cost to implement and operate (low, moderate, or high).

The final research stage was to discover relationships between the method(s) used to identify the high crash location and the recommended 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 to identify high crash locations. The overall goal was to develop engineering countermeasures specifically aimed at reducing crashes involving older drivers. Thus, this research can aid in the extensive work towards increasing seniors driving time and thus improving their quality of life.

Research Scope

As noted, the aim of this research was to combine spatially-based crash analyses and road safety investigations with a direct focus on the older driver. More specifically, the work outlines an approach for identifying high crash locations for older drivers, which were subsequently included in an older-driver themed road safety audit. The scope of this research was limited to the crash data available for the Commonwealth of Massachusetts. 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 and a statistical sampling technique must be employed. For example, Figure 3 below shows the location section on a Massachusetts Motor Vehicle Crash Police Report from 2005. Although the information in the location section of the crash report form is valid and in the right section, there is not enough information to identify the precise location of the crash.



Date of Crash 01/14/2005 | Time of Crash 1739 24HR | City/Town WARE | Motor Vehicle Crash Police Report | Number Vehicles 3 | Number Injured 1 | Speed Limit Lat. Lon. | State Police Local Police MBTA Police Other:

AT INTERSECTION: < LOCATION > NOT AT INTERSECTION:

Route# Direction Name of Roadway/Street

At

Route# Direction Name of Intersecting Roadway/Street

Also at Intersection with

Route# Direction Name of Intersecting Roadway/Street

PALMER RD

Route# Direction Address # Name of Roadway/Street

Feet N S E W of Mile Marker or Exit Number

Feet N S E W of Route# Intersecting Roadway/Street

Feet N S E W of Landmark

Figure 3. Location Section of the Massachusetts Crash Report Form

The data set used in this research project represents the most recent data which has been deemed complete by the Massachusetts Registry of Motor Vehicles (2007 and 2008). Furthermore, the crash data analyzed using the Arc GIS mapping software are only those that were geo-located, i.e. the exact crash location was identified and assigned corresponding geographic x and y coordinates. It is important to understand all elements of traffic crashes and therefore, it is crucial that officers, serving as the front lines of data collection, fill out the form accurately and in sufficient detail at the scene of every crash. Many crash reports do not provide sufficient information in the various location fields on a crash report form, resulting in inconsistencies in the crash report data and complicating studies making use of the reports. In addition to the unreliable location information, other data collection issues include missing injury severity data, poor data quality for engineering related fields, and data entry errors.

Furthermore, Massachusetts data for the average daily traffic was used in this research. This data, which is provided in the Roadway Inventory File published by the Massachusetts Department of Transportation, is regarded as poor quality and may not be reliable or accurate in many instances.

Several methods, which are summarized in the Identifying High Crash Locations section, were not utilized as the data required to perform these calculations was not readily available or regarded as good quality. For example, the Relative Severity Index (RSI) method accounts for the damage caused by the crash based on both cost and severity. Since the average comprehensive cost per crash for each crash severity level is not concrete data which is readily available, this method was not utilized to rank the ODHCL's.

The road safety investigations resulted in recommended countermeasures aimed at mitigating the older driver crash problem at the specified location. Evaluations of the crash reductions for the selected countermeasures (low, moderate, or high) were included as well as estimates of the timeframe for implementation (short, medium, or long) and predictions of the relative cost to implement and operate each countermeasure (low, moderate, or high). Although these estimates are included for each countermeasure, the effects of these measures and the validity of these estimates are outside the scope of this project.

2.0 BACKGROUND

This paper describes an application of spatially-based crash analyses and road safety investigations with a direct focus on the older driver. The paper's goal was to outline approaches for identifying high crash locations for older drivers, which were subsequently included in older-driver themed road safety investigations. The ultimate result is recommended countermeasures aimed at mitigating the older driver crash problem at the specified locations. In order to successfully complete this research it was important to gain a comprehensive understanding of the related literature in several topic areas. This included but was not limited to a review of strategies which are being implemented across the U.S. to increase older drivers' safety, FHWA's Road Safety Audit Guidelines, and a review of existing methods used to identify high crash locations.

Older Driver Countermeasures

Given the increase in population coupled with an increase age, older driver countermeasures are necessary as the current system of roads, traffic signals and controls, laws, licensing practices, and vehicles were not designed to safely and effectively accommodate their needs. The goal of these countermeasures is to successfully balance road safety with the rights and mobility of the older population. Although this research focuses on enhancing and improving the geometric design of an intersection, its surroundings, and the corresponding traffic control devices, it is important to gain a comprehensive sense of what strategies are being implemented throughout the United States to deal with the older driver challenge. For example, behavioral strategies include educating and training seniors to assess their driving capabilities and limitations through courses or outreach, helping seniors adjust to medical or functional conditions that affect driving through treatment or vehicle adaptations, identifying those who cannot drive safety and revoking their licenses, and increasing the older driver seatbelt usage (8). Table 1 provides an overview of older driver countermeasures involving communications and outreach, licensing, and traffic law enforcement as well as their associated effectiveness, use, cost, and implementation time, all of which can vary significantly by state, city, and town. In this analysis, published by NHTSA, effectiveness is measured on a five star scale depending upon the reduction in crashes or injuries attributed to the countermeasure. One star indicates limited or no high-quality evaluation evidence while a five star rating indicates that the countermeasure was shown to be effective by several high-quality evaluations with consistent results. The prevalence of the countermeasure is represented by a low, medium, or high rating. Low indicates that less than one third of states or communities have implemented the countermeasure while high indicates that more than two thirds of states or the majority of communities have implemented the countermeasure. Cost of implementation is also represented by a low, medium, or high rating. Low indicates that the countermeasure can be implemented with minimal additions to the existing facilities and equipment, staff, and training program. High indicates that new facilities and equipment, staff, or publicity are required for implementation. Lastly, time to implement is measured on a scale of short, medium, or long. Short indicates less than three months while long indicates greater than one year.

Table 1. Older Driver Countermeasures (8)

Countermeasure	Effectiveness	Use	Cost	Time
1.1 Formal courses for older drivers	★★	Low	Low	Short
1.2 General communications and education	★★	Unknown	Low	Short
2.1 License screening and testing	★★★★	High	Medium	Medium
2.2 Referring older drivers to DMVs	★★★★	Low	Medium	Medium
2.3 License restrictions	★★★	Unknown	Low	Short
2.4 Medical advisory boards	★★	High	Varies	Medium
2.5 License renewal policies	★★	Medium	High	Medium
3.1 Law enforcement roles	★★★	Medium	Varies	Varies

Older Driver Highway Design Handbook

The purpose of the *Older Driver Highway Design Handbook* is to provide transportation professionals with highway design and traffic operations information catered specifically towards appropriately accommodating older drivers. This handbook is intended to be used in conjunction with current standards and guidelines in highway design, operations, and safety for all road users and is not a replacement for any other resource. As the population increases and is becoming older, it is of critical importance to design for the older population. Furthermore, the handbook authors recognized that while the driving population loses cognitive capability and has poorer physical abilities, traffic congestion will simultaneously increase with an increase in population. While transportation professionals are aware of older driver statistics which have been produced from past crash data nationwide, a source of valuable information was not available on how to accommodate older drivers (9).

The handbook provides recommendations as well as supporting evidence and rationale for the following: at-grade intersections, interchanges (grade separation), roadway curvature and passing zones, and construction/work zones. These categories were identified as they are particularly difficult for older drivers to successfully maneuver. Subsections provide information on specific geometric, operational, and traffic control design elements. One chapter provides design element recommendations while the corresponding rational and supporting evidence for each recommended design element is provided in a subsequent chapter. This information is drawn from field studies employing older drivers, laboratory simulations, or modeling efforts as well as other research. This research focuses on at-grade intersections and roadway segments so the handbook's recommendations and supporting evidence pertaining to these chapters will be of particular relevance (9).

At-grade intersections have contributed to the most serious crashes and problems for older drivers due to their complexity and the difficulty associated with taking left turns. Additionally, horizontal curves pose a serious safety issue to older drivers as motorists are often driving too fast for the curves or are surprised by the curve alignment. It should be noted that the recommendations provided in the handbook are not new design standards or requirements but should be considered as a problem solver at older driver crash sites or during the design process to enhance safety where older drivers are expected in high volumes. It bears mentioning that every recommendation is not necessarily applicable to every scenario. It should also be noted that high cost optimal solutions with only small gains in anticipated safety are not included in this handbook. Also, although these recommendations are intended to enhance the safety of older drivers, they are not recommended if they could potentially harm other users (9).

The handbook specifies sixteen recommendations to consider when accommodating older drivers at at-grade intersections. These recommendations deal with varying intersection attributes including but not limited to channelization, intersection sight distance, intersecting angle, signage, receiving lane width for turning operations, curb radius, opposite left-turn lane geometry, signing, and delineation, pedestrian control devices, fixed lighting installations, edge treatments/delineation of curbs, medians, and obstacles, and traffic signal performance issues (9).

There are four recommendations to consider when accommodating older drivers on horizontal and vertical curves and passing zones. These recommendations involve making modifications to the pavement markings and delineation, the pavement width, the crest vertical curve length and the advance signing for sight-restricted locations, and the passing zone length, passing sight distance, and the passing/overtaking lanes on two-lane highways (9).

Application of Crash Data & RSA's

It is important to note that combining crash data and RSA's is not an entirely novel approach. In 2006, Langone explored methodologies and applications of location-based analyses for younger driver crashes in Massachusetts. This analysis yielded information on dangerous roadway characteristics and designs that contribute to young driver crash rates. The results presented methods for improving the safety of younger drivers throughout the Commonwealth of Massachusetts. Table 2 outlines the common characteristics which were identified at various roadway/intersection types following a field safety review at crash sites with a high number or younger driver crashes (10).

Table 2. Field Safety Review Observations (10)

Roadway/Intersection Type	Observation
Signalized Intersections	• Permissive left turns across several travel lanes • Limited sight distance
Segments/Corridors	• Congestion • Several access driveways • Two travel lanes per direction
Unsignalized Intersections	• Signage expectations • Speed variance
Highway Interchanges	• Several merge and diverge points

FHWA Road Safety Audit Guidelines

The Federal Highway Administration defines a Road Safety Audit (RSA) as the formal safety performance examination of an existing or future road or intersection by an independent, multidisciplinary audit team. The purpose of an RSA is to identify potential safety issues and possible opportunities for safety improvements considering all roadway users. RSAs are intended to provide a supplementary method to examine and improve safety and thus should not be misinterpreted as replacements for design quality control or standard compliance checks, traffic impact or safety impact studies, safety conscious planning, road safety inventory programs, or traffic safety modeling efforts (11). Specific objectives of an RSA include, but are not limited to the following:

• Minimizing the risk and severity of road crashes that may be affected by the existing or future roadway at a specific location or nearby network (11).

• Improving the awareness of safe design practices which are likely to result in safety benefits based upon potential safety concerns (11).

Although RSAs have been employed in other countries for some time, it is only now that they are being fully embraced across the United States as a low cost strategy to make significant safety improvements at any number of stages ranging from project development and planning through existing operation. RSAs have proven to be effective on a wide range of projects. RSAs can be customized to fit the specific goals and objectives of public agencies and are strongly recommended for implementation (11). The steps in a RSA are the following:

• Step 1 - identify project or road in-service to be audited,
• Step 2 - select RSA team,
• Step 3 - conduct a pre-audit meeting to review project information,
• Step 4 - perform field observations under various conditions,
• Step 5 - conduct audit analysis and prepare report of findings,
• Step 7 - project owner/design team prepares formal response,
• Step 8 - incorporate findings into the project when appropriate.

RSAs are a proactive method of tackling safety. RSAs are generally initiated due to stakeholder concerns or as part of frequent safety checks intended to enhance the roadway. RSAs performed in the design stage may reduce the frequency and severity of crashes and thus save money, time, and lives. Both nominal safety concepts (compliance with standards) and substantive safety concepts (crash performance) can govern where an RSA is performed (11).

It is important that FHWA's Roadway Safety Audit Guidelines are understood as they will be used as a basis for executing the field safety investigations to be conducted as part of this research effort. RSAs are commonly used and are expected to produce the best result for mitigating older driver crashes.

Identifying High Crash Locations

The Missouri University of Science and Technology is conducting a project on the identification and analysis of high crash segments on Interstate, US, and State Highway systems in Arkansas. They explored several methods of ranking high crash locations: the spot map method, crash methods, the frequency-rate method, quality control methods, crash severity methods, index methods, and Bayes methods, each with their own advantages and disadvantages (12). This list is important to this project because it forms the basis for the methods which will be explored to identify locations where older drivers are overrepresented in crashes.

The spot map method simply entails visually looking at a map of crashes to pinpoint areas containing a high frequency of crashes. These areas are then tagged as high risk areas. This method is fast and easy but can be inaccurate, especially for large areas and does not provide an ordered ranking (12).

Crash methods account for all crashes, assigning each a rank according to attributes such as crash frequency, crash density, or average daily traffic (ADT). The crash frequency method ranks crash sites based upon the number of crashes which occurred at a particular location. The crash density method ranks crash sites based upon the crash frequency for a given segment length of roadway. The crash rate method accounts for both the traffic volume and the crash frequency at the site. This is calculated using the following equation:

$$\text{Crash Rate} = \frac{n(t)}{q(t)}$$

where:

n(t) = the number of crashes at a location during a specified time t, and
q(t) = the traffic volume at the location during time t.

A multiplier is generally used for simplicity to increase the resolution. The crashes are then ranked based on the rate calculated for each site. A spot crash rate is used to find the number of crashes per million vehicles entering an intersection. The spot rate is calculated using the following equation:

$$R_i = \frac{2(A)(1{,}000{,}000)}{(T)(V)}$$

where:

R_i = spot crash rate expressed in crashes per million vehicles entering a spot of highway,
A = total number of crashes during the duration of the study,
T = time period in days, and
V = total average daily traffic entering and departing the intersection.

The locations are then ranked based on the spot rate calculated for each site. Furthermore, the section rate divides a larger section of highway into smaller sections, accounting for both volume and length. The section rate is computed using the following equation:

$$R_s = \frac{(A)(100{,}000{,}000)}{(T)(V)(L)}$$

where:

R_s = section rate in crashes per hundred million vehicle miles,
A = total number of crashes during the duration of the study,
V = average annual daily traffic (AADT) on a section (vehicles per day),
T = period (days) for which crashes are counted, usually 365 days, and
L = length of section in miles.

The sites are then ranked based upon the section rate calculated for each site (12).

The frequency-rate method combines the crash frequency, crash density, and crash rate method. The crash frequencies and densities are calculated and the crash rate is then used to produce a list of high crash locations ordered by traffic volume (12).

The quality control method compares the crash frequencies, densities, and rates at each site to predetermined averages for roadways having similar attributes, accounting for differences in the roadway types. The number quality control method uses a statistical analysis to obtain the frequency/density of a site and then compares it with the mean frequency/density for similar sites. The following formula computes the critical crash rate:

$$F_c = F_a + k\sqrt{\frac{F_a}{M}} + \frac{1}{2M}$$

where:

F_c = critical rate for a particular location,
F_a = average crash frequency/density for all road locations of like characteristics,
K = probability factor determined by the level of statistical significance desired for F_c, and
M = number of vehicles traversing particular road section or number of vehicles entering a particular intersection during the analysis period.

The rate quality control method uses a statistical test to compare the crash rate of a particular site to a site with similar attributes. The following formula computes the critical crash rate:

$$R_c = R_a + k\sqrt{\frac{R_a}{M}} + \frac{1}{2M}$$

where:

R_c = critical rate for particular location (crashes per million vehicles or crash per million vehicle-km),
R_a = average crash rate for all road locations of like characteristics (crashes per million vehicles or million vehicle-km),
K = probability factor determined by the level of statistical significance desired for R_c, and
M = number of vehicles traversing particular road section (millions of vehicle-km) or number of vehicles entering a particular intersection (millions of vehicles) during the analysis period.

The advantage of the quality control method is that it utilizes the AADT and a statistical test to improve the ranking process. However, this method is vague with respect to the constant k and does not account for crash severity (12).

Crash severity methods integrate crash severity into crash frequency and density methods to give crashes with fatalities or injuries a higher ranking. The Equivalent Property-Damage-Only method assigns a weight based on crash severity so that those resulting in a fatality or injury are given more attention than those only resulting in property damage. Volume, however, is not accounted for in this method. The EPDO index is computed using the following equation:

$$EPDO\ Index = [w_k K + W_A A + W_B B + W_C C + P]$$

The severity index is computed using the following equation:

$$SI = \frac{[w_k K + W_A A + W_B B + W_C C + P]}{T}$$

where:

SI = severity index for the site,
W = the respective weight coefficients,
K = frequency of fatal crashes at the site,
A = crash frequency involving A-type injures at the site,
B = crash frequency involving B-type injuries at the site
C = crash frequency involving C-type injuries at the site,
P = frequency of PDO crashes at the site, and
T = total crashes at the site.

The EPDO rate is computed using the following equation:

$$EPDO\ Rate = \frac{[EPDO\ Index * \ 10^6\ or\ 10^8}{[(Exposure\ per\ day) * Days]}]$$

The Relative Severity Index (RSI) Method accounts for crash damage based on cost and severity. Volume is also not considered in this method. The RSI value is computed using the following equation:

$$RSI = \frac{[C_K K + C_A A + C_B B + C_C C + C_P P]}{(K + A + B + C + P)}$$

where:

RSI = Relative Severity Index for the site,
C = the average comprehensive cost per crash for a crash of severity level “i” from K through P,
K = frequency of fatal crashes at the site,
A = crash frequency involving A-type injuries at the site,
B = crash frequency involving B-type injuries at the site,
C = crash frequency involving C-type injuries at the site, and
P = frequency of PDO crashes at the site (12).

Index Methods combine several methods by applying weights and adding them together to rank the crashes. The Weighted Rank Method calculates an index using up to five indicators such as crash frequency, crash density, crash severity, and the number of lanes. Weights are assigned to indicators and they are then added. This is useful as the specific indictors can be selected according to project objectives. Many indicators can reduce errors but this method can be subjective. The Crash Probability Index (CPI) Method is similar to the weighted rank method in that it uses different indicators and can be adjusted to fit agencies priorities. However, if a factor is below the average penalty points are allotted. They are added up and the locations with the highest number of penalty points are designated as high crash locations. This method takes into account severity and reduces error but can be subjective and time consuming. The Iowa Method is nearly identical to the CPI method but uses only three ranking lists (frequency rank, rate rank, and severity rank) that are combined into one list. The severity rank is based on loss at a crash site so fatalities are allotted a high dollar amount and minor injuries a lower dollar amount. This method, like the CPI method, reduces misleading results for high and low volume sites and includes severity (12).

The Bayes method computes a Safety Performance Function (SPF) to estimate the normal expected number of crashes which can be used to estimate the expected number of future crashes. Hierarchical Bayes ranks roadway segments according to crash frequency, the number of fatalities, and crash severity. This is done using a Poisson distribution and a cost function for crash severity. This approach reduces misleading results and random variation in crash counts. The Empirical Bayes (EB) Method calculates the normal expected number of crashes using a safety performance function combining it with the crashes resulting in an estimate of site-specific expected number of crashes. This method is very precise but is time consuming and a lot of effort compared to other methods (12).

NCHRP Report 500 – A Guide for Reducing Collisions Involving Older Drivers

The AASHTO Strategic Highway Safety Plan works to decrease fatalities on the nation’s roadways through cost effective countermeasures which have proven to minimize crashes. Volume 9 of the NCHRP Report 500: A Guide for Reducing Collisions Involving Older Drivers provides strategies which can be implemented to reduce the number of crashes involving older drivers. After defining the older driver challenge, this report discusses various strategies aimed at mitigating the problem. The strategies are categorized under five objectives which aim to provide a comprehensive approach to deal with the older driver challenge (13):

- Plan for an aging population
- Improve the roadway and driving environment to better accommodate older driver's special needs
- Identify older drivers at increased risk of crashing and intervene
- Improve the driving competency of older adults in the general driving population
- Reduce the risk of injury and death to older drivers and passengers involved in crashes

Although this research focuses on the strategies relating to the objective of improving the roadway and driving environment to better accommodate older driver's special needs, it is important to have a widespread sense of the range of strategies which exist. Furthermore, this report provides a description of each strategy, the associated implementation timeframe and relative cost of each strategy, and a guide for implementing the AASHTO Strategic Highway Safety Plan. This report will be the basis for evaluating the countermeasures which are recommended at each ODHCL (13).

3.0 METHODOLOGY

Five essential tasks were identified as critical to the goals of this research effort.

• *Task 1: Literature Review;*

In order to better understand the nature of the challenges inherent to accommodating older drivers, it is imperative to review previously implemented measures which successfully contributed to reductions in older driver crashes. Particular emphasis was given to highway design and traffic operations measures as these are most relevant to the efforts of this research project. A review of the FHWA's Roadway Safety Audit Guidelines was conducted as these are an important reference for completing the steps in Task 4: Field Safety Review. Methods for identifying high crash locations were also explored in this task. The results of this Literature Review are presented above in the 2.0 BACKGROUND section.

• *Task 2: Crash Data Analysis;*

In order to develop a general understanding of the crash attributes common to older driver crashes, it was necessary to review and analyze crash history data. This analysis allowed for the comparison of older driver crashes to those involving other age groups. Population statistics were obtained from the US Census Bureau. Crash data and other relevant data were obtained from various agencies through the UMass Safety Data Warehouse. The UMass Safety Data Warehouse was created by the UMass Traffic Safety Research Program (UMassSAFE) at the University of Massachusetts Amherst as a tool to conveniently store and access crash-related data in order to optimize the use of highway safety data. It is extremely valuable in understanding crash characteristics and in identifying critical problems. 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, among others. The use of assorted, diverse data allows for truly comprehensive analyses of highway safety problem areas. The schematic below shows the variety of data that is currently available in the UMass Safety Data Warehouse.

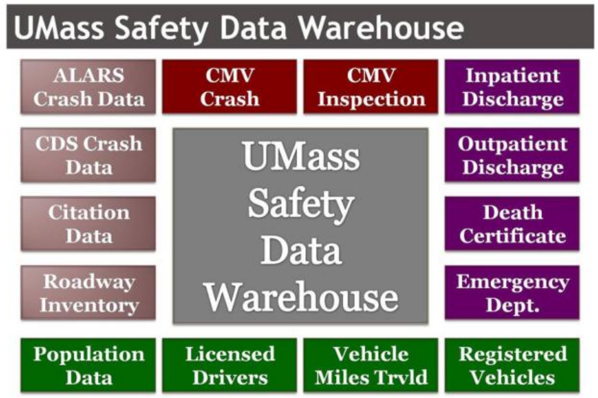


Figure 4. UMass Safety Data Warehouse

This research project utilized 2007 and 2008 Massachusetts reported crash data involving an older driver (age 65+) as well as those involving a driver in the control group (age 35-55). A reportable motor vehicle crash 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 and facts. For the purpose of this study, an older driver was defined as a person 65 years of age or older; an oldest driver was defined as a person 85 years of age or older. 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. As discussed in the Research Scope section above, approximately 85% of crashes can be successfully geo-located and assigned relative x and y coordinates. Arc Map allows the user to explore data within a data set, symbolize features accordingly, and create maps. Massachusetts "shapefiles" including community boundaries (towns) and EOT Major Roads were obtained from the Mass GIS website, www.mass.gov/mgis/mapping.htm. In addition, it is possible to create and manipulate data sets from the UMass Safety Data Warehouse to include a variety of information.

• *Task 3: Identify ODHCL's;*

Several existing methods were applied to the crash data sets to identify ODHCL's. 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 is available for download on the Massachusetts Department of Transportation website. 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. These generally distinct data sets merged together are used to identify problematic locations with known roadway characteristics and assess the effectiveness of implemented countermeasures. Yet the precise manner in which data sets should be linked for analysis purposes and the extent to which data can be uniformly analyzed across locations remains an area of continued research. This research links these data sets to create maps to spatially analyze the data, applying established HCL methods which have been utilized for years to identify HCL's for a comprehensive analysis.

Transportation professionals generally agree that intersections are particularly difficult for older drivers to maneuver. This research attempts to identify older driver HCL's at both intersections and road segments through various frequency, density, rate, and severity methods. Various methods were used in order to explore the best way to find intersections and roadway segments where older drivers were overrepresented in crashes.

The crash data included on the crash report form which was queried from the UMass Safety Data Warehouse is derived from the reports filed by police officers responding to the crashes. The unique identifier in this data set is at the person level, i.e. the crash number followed by an additional number which indicates the specific driver of interest. The data set includes fields on the crash report form such as the crash date and time, town, county, the manner of collision, injury status, age, sex, and the driver contributing code for each involved motorist. This data set also contains some fields which are not included directly on the crash report form but are later identified by other agencies such as the Massachusetts Department of Transportation or the UMassSAFE Traffic Safety Research Program. These fields include the crash severity code and the geographic reference data. Although, the x and y coordinates allow each driver involved in a crash to be pin-pointed on a map, this data set does not include the roadway segment ID on which the crash occurred, making the more specific location information and roadway characteristics unknown. Although the crash number with its corresponding Roadway Segment ID number is not yet available for querying from the UMass Safety Data Warehouse it is available from the Massachusetts Department of Transportation and the UMassSAFE Traffic Safety Program as a usable copy of this file which contains all reportable crashes in the Commonwealth. Using the data queried from the UMass Traffic Safety Warehouse in conjunction with this file, both of which contain a crash number, the datasets were joined using Microsoft Access. The result is the specific data of interest, i.e. drivers age 65+ and age 35-54 involved in geo-located intersection and roadway segment crashes with the corresponding roadway segment ID where the crash occurred on for each driver.

Specific location information and roadway characteristic information is also important to this analysis. This information is included in a Massachusetts roadway inventory dataset provided through the Massachusetts Department of Transportation website. The unique identifier in this information is a roadway inventory ID. The choice of identifier is inconvenient for this analysis as the information contained in the queried data set only contains the roadway segment ID and, since a roadway segment is comprised of multiple roadway inventories, roadway characteristics may vary throughout the segment. For this reason, much of the roadway inventory file was not compatible with the crash data file as there was not a common identifier in the data sets preventing joining the data. It was decided that for this analysis the required fields from the roadway inventory file were the average daily traffic and the segment length. The roadway segment length was obtained by adding the lengths of each roadway inventory which together comprise the roadway segment. It was determined that within this data set the average daily traffic field was inconsistent and of poor data quality as many of the roadway inventories had an average daily traffic of zero or were left blank. It was decided that the best option was to use the maximum average daily traffic for each roadway segment as this would provide a more reasonable data set. For example, suppose a roadway segment encompassed three separate roadway inventory records, i.e. a roadway segment was split into three separate links and the data within the file was collected separately for each link. Now suppose one record reported an average daily traffic of 0 vehicles per day, one an average daily traffic of 500 vehicles per day, and one and average daily traffic of 10,000 vehicles per day, an average daily traffic of 10,000 vehicles per day was used in this analysis for the roadway segment as a whole. Although this data is of poor data quality and should not solely be relied upon, it enables crash rates to be calculated, and therefore, exposure can be accounted for in this analysis. Once the roadway inventory file was significantly reduced and altered as discussed above, this file was joined with the crash data file using the roadway segment ID field contained in both data sets. The final result is the road segment identifier along with the maximum average daily traffic on the roadway segment and the length of the roadway segment attached to each driver record queried from the UMass Safety Data Warehouse. This information is critical as it allows for density and rate calculations.

A separate HCL identification process was used for at intersections and roadway segments, due to older drivers' particular difficulty with navigating through intersections. The *Older Driver Highway Design Handbook* makes this same distinction. The high crash roadway segments and intersections described within the 4.0 RESULTS & ANALYSIS section are identified as a number which is the Roadway Segment ID it was assigned by the Commonwealth of Massachusetts' Office of Geographic Information. To separate the drivers involved in a crash on a roadway segment from those involved in a crash at an intersection, the "roadway intersection type" field on the Commonwealth of Massachusetts motor vehicle crash report form was utilized. 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 high crash locations at intersections while drivers involved in a crash in which the "roadway intersection type" field on the crash report form indicated the crash occurred "not at junction" were included in the analysis for high crash locations for roadway segments.

To facilitate this process, separate maps were generated to present drivers involved in a crash on a roadway segment and those at an intersection. Two types of markers separate motorists age 35-55 involved in crashes in 2007 and 2008 and motorists 65 years of age or older for the 2007 and 2008 datasets. Motorists age 35-55 were selected as the control group. Motorists under the age of 25 were not included as younger drivers are also considered a high risk driving population and their inclusion might have overly generalized the recommendations produced by this study.

Once the data sets were linked and the maps were created, locations including both intersections and roadway corridors/segments were initially identified as HCL's in accordance with the following criteria:

• Intersections: a minimum of five older drivers (age 65+) involved in a crash at the junction and/or within 0.25 miles on any of the approaches;

• Segments: a minimum of four crashes along a length of the roadway assigned a roadway segment identifier defined using the EOTROADS_ARC file on the Mass GIS website.

This data join was thoroughly evaluated to ensure crashes linked correctly and that all crashes remained present through the process.

Next, the identified ODHCL candidates were compared to the frequency of drivers in the control group involved in crashes. This was done by calculating a statewide ratio of older drivers involved in crashes to drivers age 35-55 involved in crashes and comparing it to the local ratio at each location meeting the criteria presented above. A ratio of 1 to less than the statewide ratio was identified as a location in which older drivers are overrepresented in crashes while those with a ratio of 1 to greater than the statewide ratio was identified as a high crash location for all road-users. Next, existing high crash location calculations were conducted to further determine specific problem locations. Several methods, presented in the literature review, were utilized and compared in order to identify the methods most appropriate for the present research. These methods included the frequency method, density method (for roadway segments only), rate method, section rate method (for roadway segments only), EPDO index method, severity index method, and the EPDO rate method. As noted above these analyses were conducted separately for roadway segments and for intersections which met the initial criteria filter presented above. 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. Summary tables were then produced for each method showing the "worst" results. A compiled summary table shows the "worst" results for each method in one table. 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.

The final product of this analysis was a list of HCL's involving older drivers or locations where older drivers were overrepresented based upon several methods. The information obtained from this task was used to complete Task 4.

• *Task 4: Road Safety Investigations; and*

Several high crash location sites with varying characteristics were selected as candidates for road safety investigations. The road safety investigations 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 conducted with less emphasis on formality. Following these field safety reviews, 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*. Additionally, photographs were taken of problem areas and the flow of traffic and/or traffic control device was observed Engineering recommendations to improve the operation and/or design of the site was included in the documentation. 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.

• *Task 5: Documentation of Findings.*

The results and recommendations from this research were documented in the form of a Master's Thesis in accordance with the University of Massachusetts Amherst guidelines and policies (14).

4.0 RESULTS & ANALYSIS

Crash Data Analysis

Demographic studies show that the elderly population in Massachusetts will grow steadily over the next decade. As such, the Commonwealth will be confronted with a host of new challenges regarding the aging driving population, which continues to be an ongoing concern in Massachusetts. In order to develop a comprehensive plan to address these challenges, an integrative understanding of older driver crash attributes must be established. The following provides an overview of the results from a crash analysis performed on Registry of Motor Vehicles (RMV) crash data and other relevant datasets.

Figure 5 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 intersections and roadway segments that experience an overrepresentation of older drivers involved in crashes, hopefully leading to mitigation strategies.

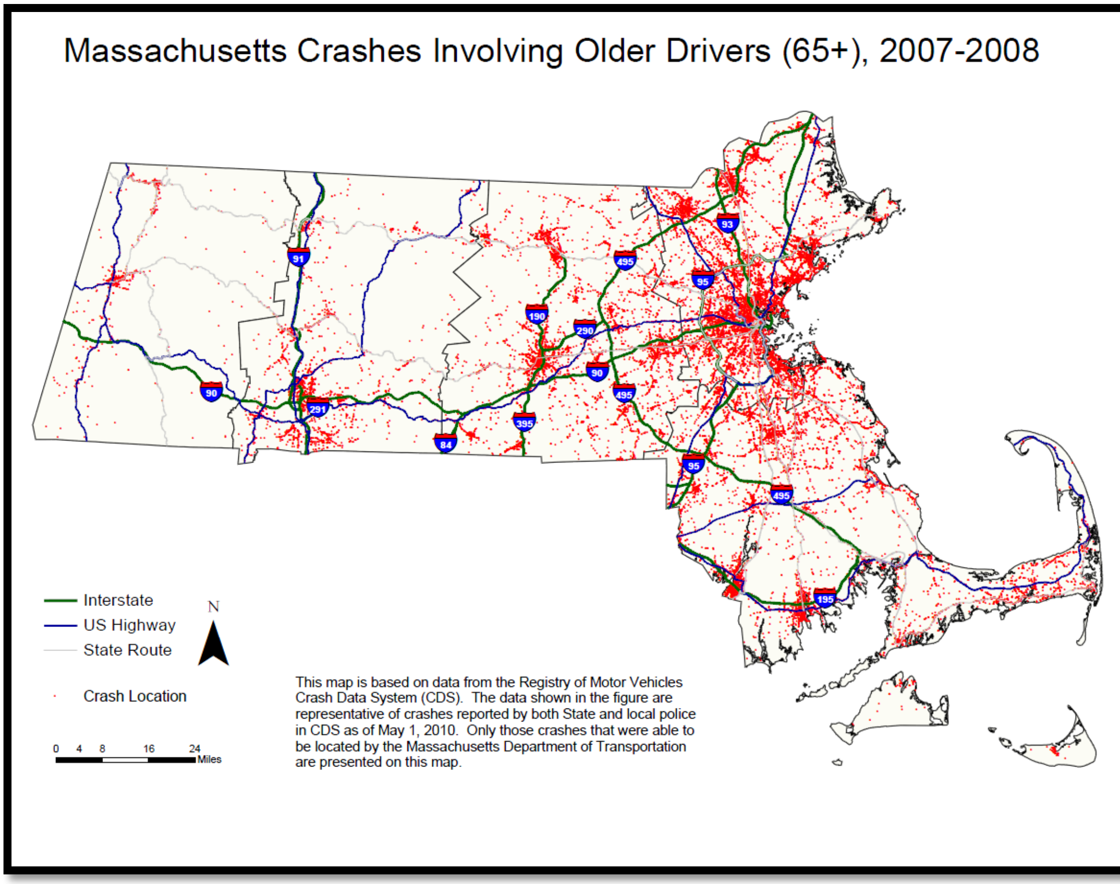


Figure 5. Massachusetts Crashes Involving Older Drivers (65+), 2007-2008

Understanding where the most serious crashes involving older drivers (those involving injuries and fatalities) are occurring is an important part of developing a solution. Figure 6 shows the location of all crashes involving older drivers resulting in injuries or fatalities in 2007 and 2008 with known locations. Crashes resulting in fatalities are represented by large red dots and crashes resulting in injuries are represented by smaller purple dots. As expected, the clustering is similar to that of the map of all crashes involving older drivers. However, it is important to note that older driver fatalities are clearly a problem across the state in urban, suburban, and rural communities.

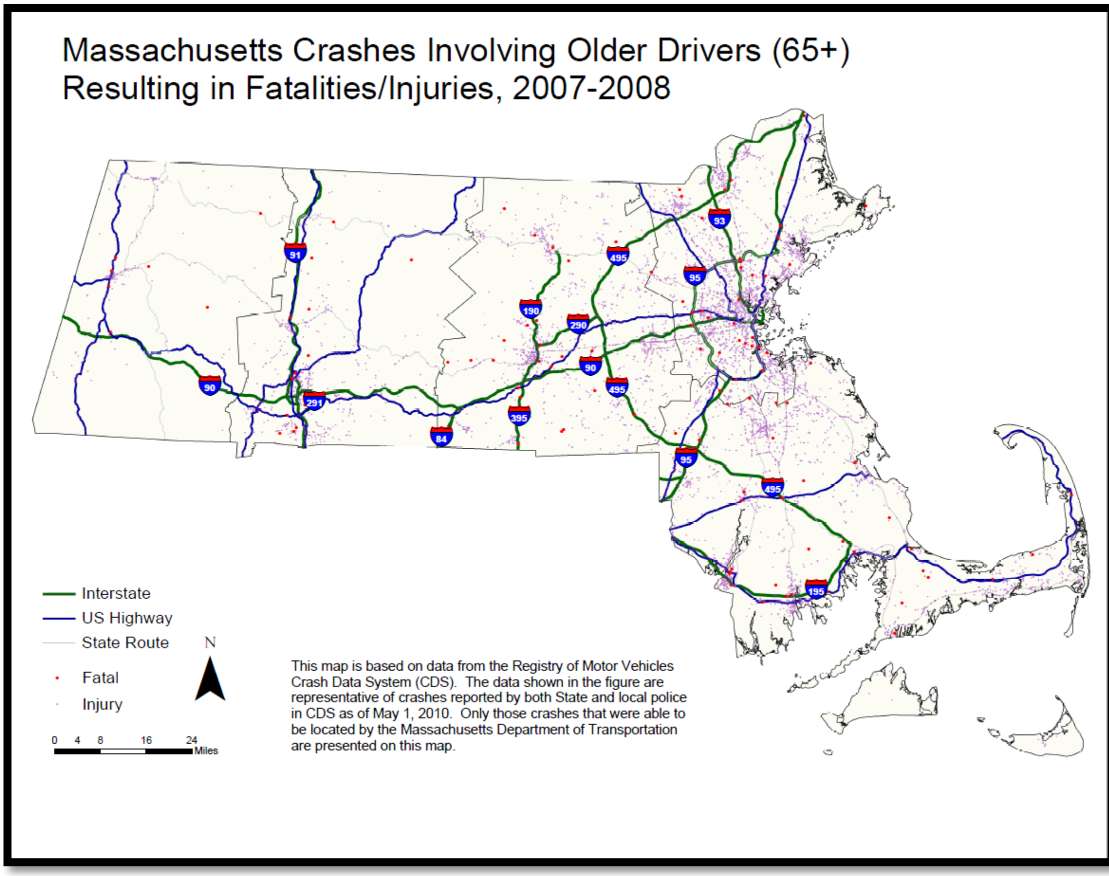


Figure 6. Massachusetts Crashes Involving Older Drivers (65+) Resulting in Fatalities/Injuries, 2007-2008

As drivers age within the population their driving characteristics change. Another step in location analysis was to analyze the older (age 65+) and oldest (age 85+) drivers separately. Figure 7 shows the location of all crashes involving older drivers that resulted in injuries or fatalities in 2007 and 2008 with known locations. Crashes resulting in fatalities or injuries in which the driver was 65 to 84 years of age are represented by large blue dots and crashes resulting in fatalities and injuries involving drivers 85 years of age or older are represented by smaller orange dots. As expected, the clustering is again similar to that of the map of all crashes involving older drivers. A more in depth spatial analysis will pinpoint specific areas with high crash rates among the older driving community.

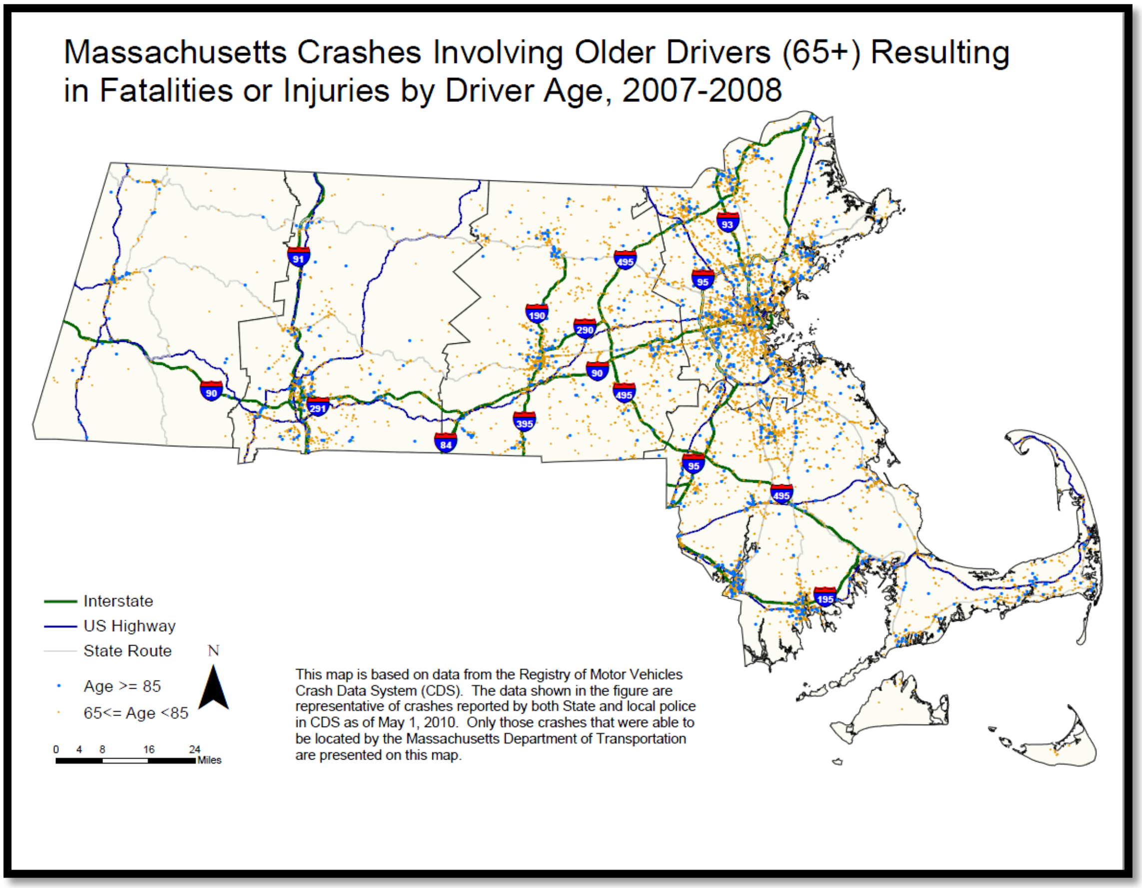


Figure 7. Massachusetts Crashes Involving Older Drivers (65+) Resulting in Fatalities or Injuries by Driver Age, 2007-2008

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 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 8 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.

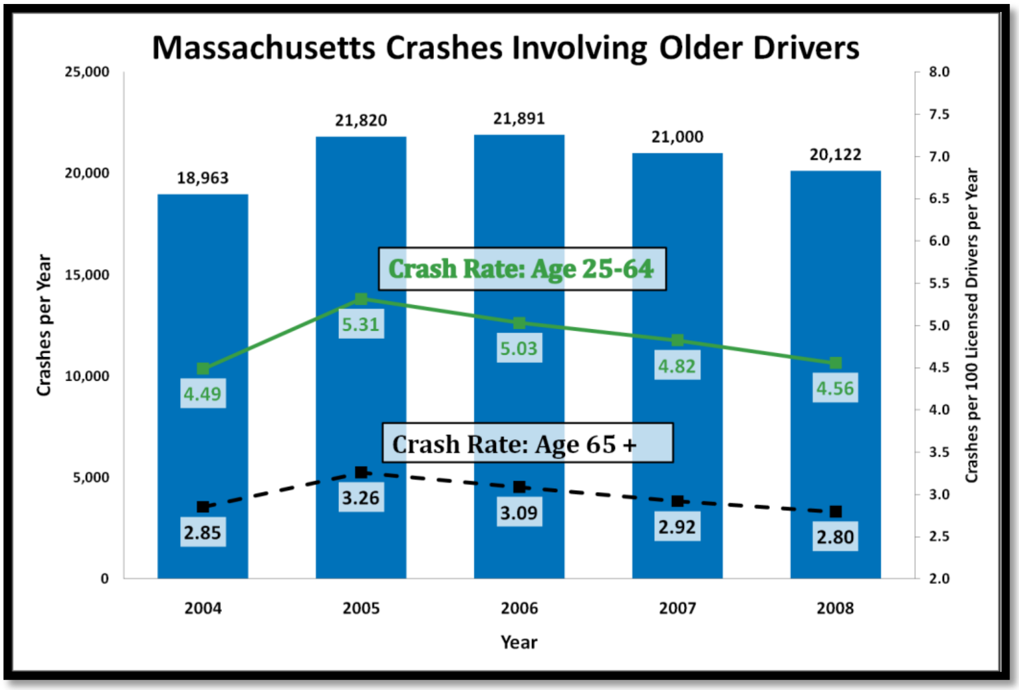


Figure 8. Massachusetts Crashes Involving Older Drivers

The older population experiences a disproportionately high number of fatalities due to traffic crashes. In Massachusetts in 2008, there were 74 traffic fatalities involving individuals 65 years of age or older. 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. This trend is largely due to the fact that relatively minor injuries can lead to potentially life threatening injuries in seniors (15).

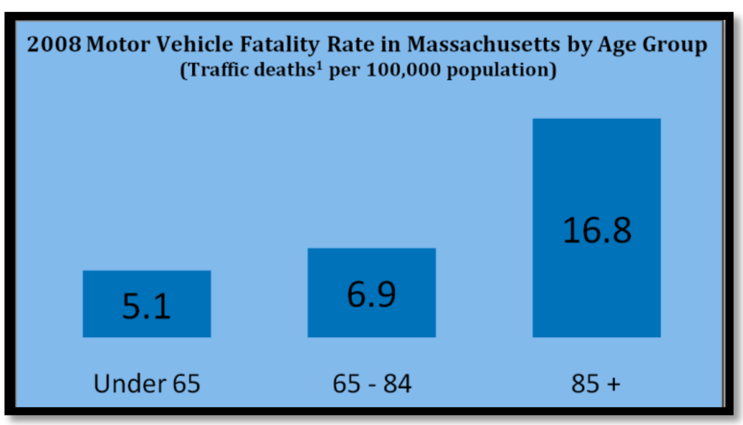


Figure 9. 2008 Motor Vehicle Fatality Rate in Massachusetts by Age Group (15)

Reported crashes vary in severity from property damage only to non-fatal and fatal injuries. In 2007-2008, the percentage of the most severe crashes (those involving fatal injuries) is greater for older drivers (0.30 percent) than a control group of drivers age 35-55 (0.19 percent). Additionally, this percentage increases with driver age within the older driver population.

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. Figure 10 shows the specific types of intersections in which these crashes occurred.

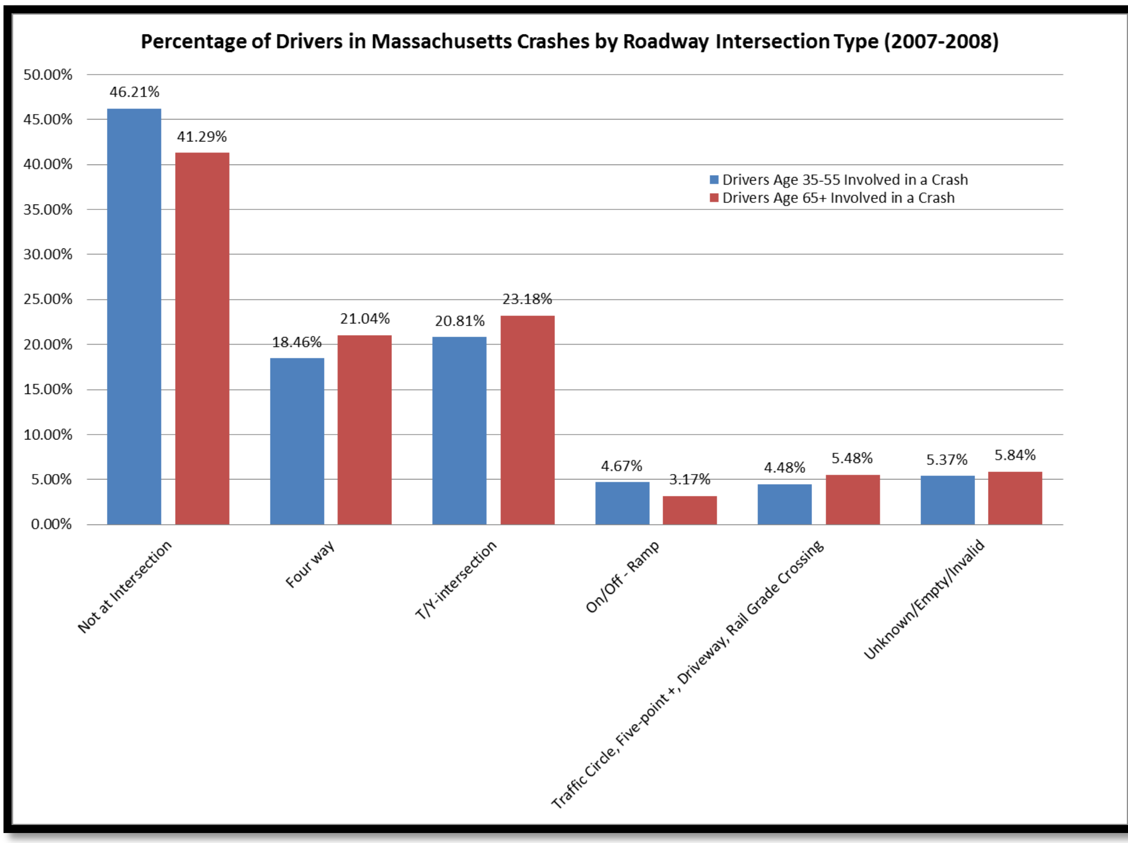


Figure 10. Percentage of Drivers in Massachusetts Crashes by Roadway Intersection Type (2007-2008)

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 35-55 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 rest of the adult population. This type of crash is often associated with speeding, following too closely, and driver inattention.

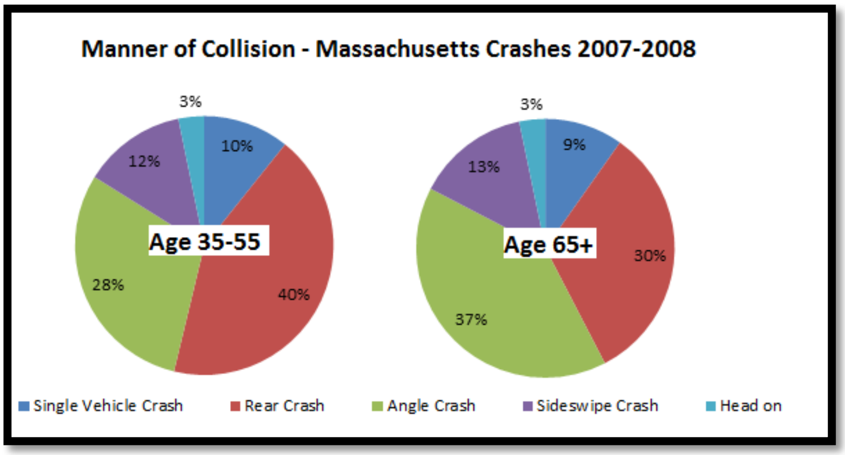


Figure 11. Manner of Collision – Massachusetts Crashes 2007-2008

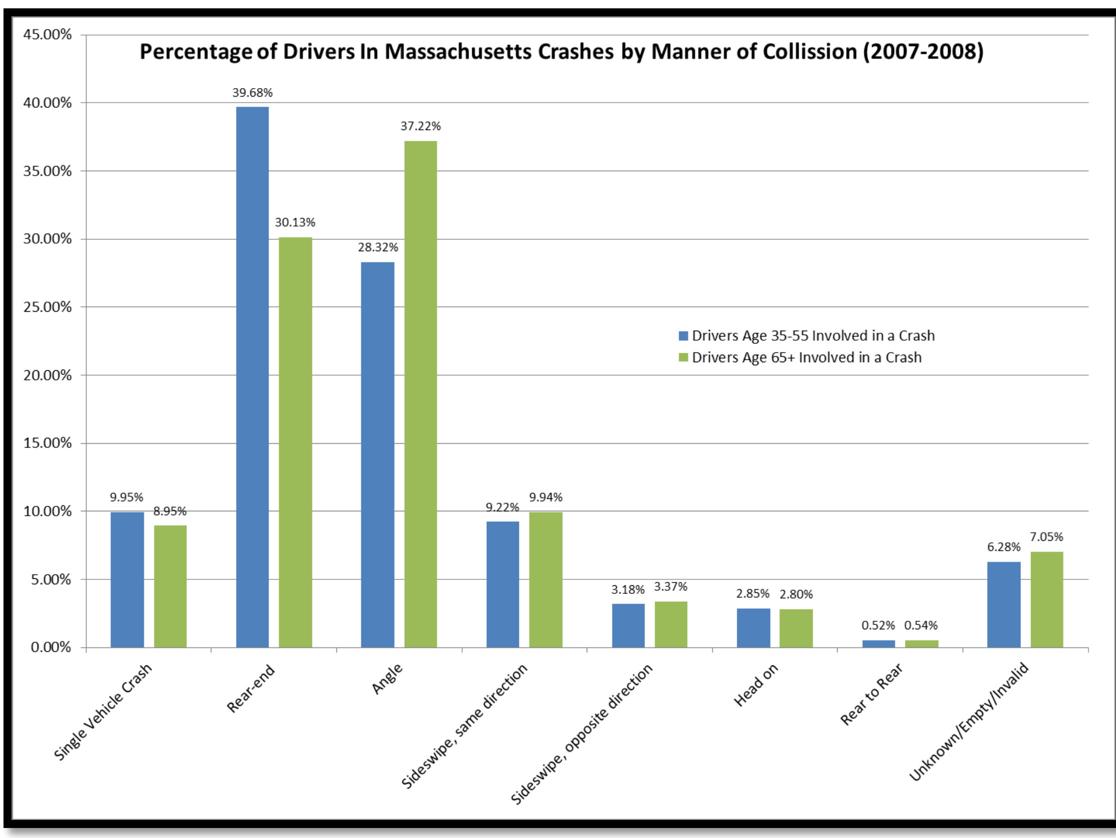


Figure 12. Percentage of Drivers in Massachusetts Crashes by Manner of Collision (2007-2008)

Driving at dusk and after dark presents a special set of challenges to older drivers. However, Massachusetts crash data from 2007 to 2008 suggest that most crashes involving older drivers do not occur at this time 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 rest of the adult population, where most crashes occur during the work day, following the AM and PM traffic peaks. The figure below shows the percentage of crashes occurring each hour for the older as well as the adult driver populations. 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.

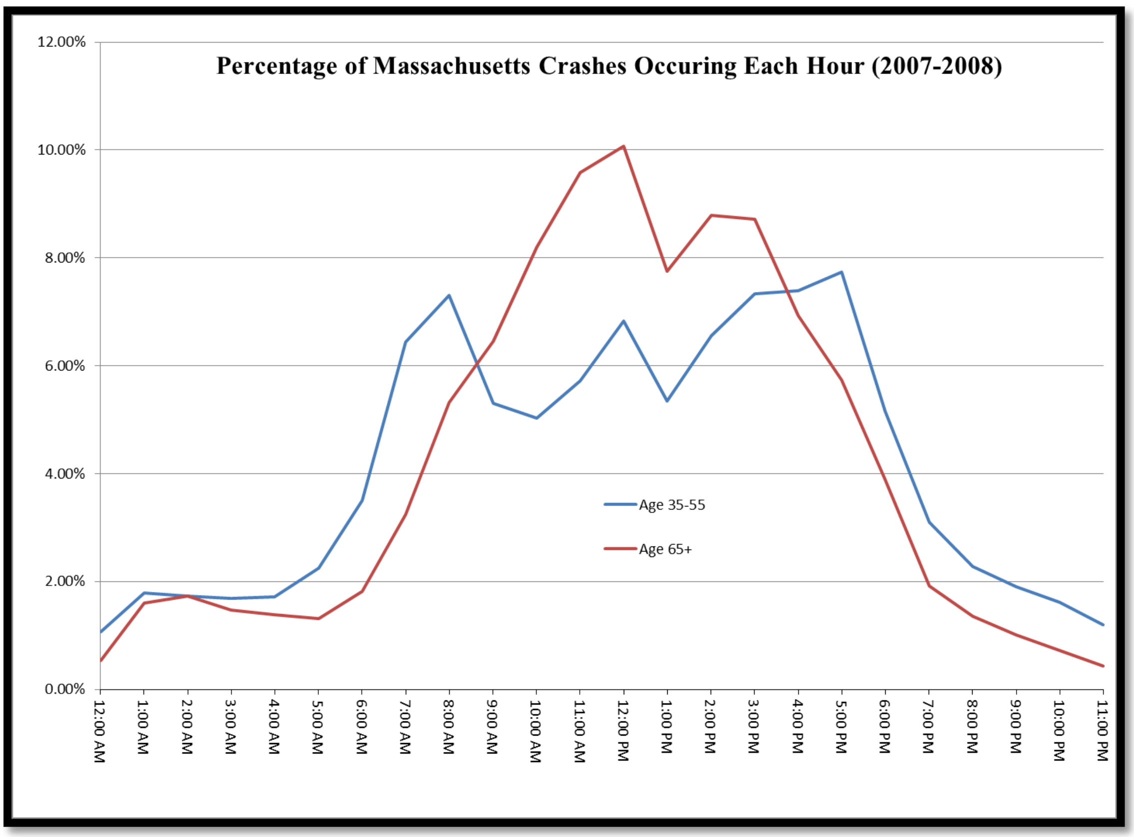


Figure 13. Percentage of Massachusetts Crashes Occurring Each Hour (2007-2008)

While there are a number of actions a driver can take that result in a crash, sometimes the crash happens even if the driver has taken no improper actions at all. Analyzing Massachusetts crashes from 2007 to 2008, where the contributing driver factor was noted, there are a number of trends that show the differences between driving behaviors of drivers of different ages. For the 35 –55 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. In other words, 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 much more frequently (8.8 percent as compared to 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). 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 ODHCL’s

The high crash location identification procedure differs for intersections and roadway segments. The high crash roadway segments and intersections below are represented by a unique numeric identifier which parallels the Roadway Segment ID assigned by the Commonwealth of Massachusetts’ Office of Geographic Information. The “roadway intersection type” field on the Commonwealth of Massachusetts motor vehicle crash report form was used to separate the drivers involved in a crash on a roadway segment from those involved in a crash at an intersection. 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 at intersection HCLs while drivers involved in a crash in which the “roadway intersection type” field on the crash report form indicated the crash occurred “not at junction” were included in the analysis for roadway segment HCLs.

The total number of older drivers (age 65+) in Massachusetts reported crashes in 2007 and 2008 was **41,170** while the total number of drivers in the selected control group (age 35-54) was **175,403**. A reportable motor vehicle crash 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. For purposes of this analysis, crash data missing their geo-location information were discarded. In this data set, **86.6 percent (35,662)** of the older driver (age 65+) crash records contained the required information. A similar fraction, **85.9 percent (150,641)** , of the control group (age 35-54) records contained the required location information Although the geo-location requirement reduces the sample size for this analysis, the sample remains large and will provide an accurate sense of intersections and roadway segments which are posing challenges for older drivers.

The sample sizes of drivers involved in intersection and roadway segment crashes are presented in Table 3 for both the older age group (age 65+) as well as the control age group (age 35-54).

Table 3. Sample Sizes of Drivers Involved in Intersection and Roadway Segment Crashes, 2007-2008

	Roadway Segment	***Intersection***	***Unknown***	***Total***
Older Driver (Age 65+)	14,202	19,788	1,672	35,662
Control Drivers (Age 35-54)	67,618	76,517	6,506	150,641

An additional **4.7 percent (1,672 records)** of the older driver crashes and **4.3 percent (6,506 records)** of the control group crashes reported the "roadway intersection type" field as unknown, invalid, or empty. As noted above, this field is required for this analysis and thus the sample size must further be reduced to remove these drivers.

Within this process the data set size was slightly reduced further as in some cases the crash in which a driver of interest was involved could not be linked to a roadway segment ID. Furthermore, there were some cases in which no average daily traffic was recorded for a roadway segment of interest. Table 4 summarizes this data reduction and presents the sample size of the final data set used to find the high crash locations at intersections and roadway segments for the drivers of interest.

Table 4. Final Data Set Used in Analysis

	Drivers in geo-located, reported Ma crashes	***Crash could not be linked to Rd segment ID***	***Did not have an ADT value***	***Total***
Older Driver (Age 65+) Roadway Segment	14,202	100	62	14,040
Control Drivers (Age 35-54) Roadway Segment	67,618	564	285	66,769
Older Driver (Age 65+) Intersection	19,788	80	132	19,576
Older Driver (Age 65+) Intersection	76,517	423	423	75,671

Roadway Segments

The aim is to ultimately develop a list of roadway segments with the potential for increased safety focused upon the older driver using several existing high crash location methods. The methods utilized included the age 65+ and age 35-55 frequency method, the age 65+ and age 35-55 density method, the age 65+ and age 35-55 crash rate method, the age 65+ and age 35-55 section rate method, the age 65+ EPDO index method, the age 65+ severity index method, the age 65+ EPDO rate method, and the age 65+ ‘average of methods’ method. This combination of methods allow for the comparison between the older driver age group (age 65+) and the control age group

Roadway segments were initially identified as a high frequency crash location if a minimum of **4** older drivers (age 65+) were involved in a crash on the roadway segment. 248 locations for the older driver age group were identified using this criterion. However, it was then discovered that many of these roadway segments occurred on an interstate. It was decided that interstate locations were outside the scope of this project and thus should be removed. After the removal of the roadway segments on interstates, there were a total of **179** roadway segments in which a minimum of four older drivers were involved in a crash. These 179 roadway segments provide the basis for next analysis in which several existing HCL methods with be performed. Each of the HCL identification methods discussed below was performed on this set of 179 roadway segments. In order to perform the high crash location methods on these segments for the control group, the frequency of drivers involved in a crash within this control age group was identified for each of the selected segments. For each HCL identification method performed, the four highest ranking roadway segments were selected as candidates for road safety investigations. The results of these investigations are presented in the Roadway Segment Road Safety Investigations section.

Table 17 provides the complete list of the roadway segments which ranked in the top four for each HCL identification method. It should be noted that if the fourth ranking had multiple roadway segments (for example - the fourth ranking for the age 65+ crash rate method had three roadway segments in which the crash rate was identical in value) all the identified segments were included in the summary table.

The age 65+ frequency method was based on the number of older drivers who were involved in a crash on a particular roadway segment. A ratio was calculated for each roadway segment to determine how many drivers in the control age group (age 35-54) were involved in a crash on a particular roadway segment for every one older driver (age 65+) involved in a crash on the same segment. The ratio for each roadway segment could then be compared to the statewide ratio. The statewide ratio was found to be

14,040: 66,769 or 1: 4.76. This statewide ratio was then compared to each of the 179 roadway segments in which greater than four older drivers were involved in a crash. Those roadway segments with a ratio 1: <4.76 were identified as segments in which older drivers were over-involved in crashes while roadway segments with a ratio of 1: >4.76 were identified as HCLs for all road users. Given that the locations were initially identified by the number of older drivers involved in a crash on each roadway segment, the majority **(97.21 percent)** of the 179 roadway segments were identified as roadway segments with an over-involvement of older drivers involved in crashes. Table 5 shows the top four results after conducting the age 65+ frequency method.

Table 5. Age 65+ Frequency Method Results – Roadway Segments

Rd Segment Id	***Age 65+ Frequency***	***Rank***	***City/Town***	***Street Name***	***Ratio (Older: Control)***
396861	12	1	Wareham	Cranberry Highway (Route 6)	1:1.417
18353	10	2	Attleboro	Washington Street (Route 1)	1:3.1
123201	10	2	East Bridgewater	Bedford Street (Route 18)	1:0.7
259307	10	2	Natick	West Central Street (Route 135)	1:2.1

The frequency method was also performed for the control group separately but using the same roadway segments in which greater than four older drivers were involved in a crash. There were a lot more than 179 roadway segments in which greater than four drivers age 35-54 were involved in a crash but given that this research is focused upon the older driver these roadway segments were not considered.

Table 6. Age 35-55 Frequency Method Results – Roadway Segments

Rd Segmen t Id	***Age 35-55 Frequency***	***Rank***	***City/Town***	***Street Name***	***Ratio (Older: Control)***
180891	46	1	Hingham	Pilgrim Highway (Route 3)	1:5.11
70091	33	2	Braintree	Pilgrim Highway (Route 3)	1:8.25
279865	33	2	North Andover	Turnpike Street (Route 114)	1:6.6
18353	31	3	Attleboro	Washington Street (Route 1)	1:3.1

The age 65+ density method is the number of drivers age 65+ involved in a crash on a particular roadway segment per the length of the segment. The lengths of the 179 roadway segments vary significantly. Table 7 presents the top four results after conducting the density method. The results correspond to the smallest roadway segments within the data.

Table 7. Age 65+ Density Method Results – Roadway Segments

Rd Segment Id	***Age 65+ Frequency***	***Segment Length***	***Density (per mile)***	***Rank***	***City/Town***	***Street Name***
137755	4	0.0110	363.64	1	Fall River	Brightman
85364	4	0.0187	213.90	2	Cambridge	Mount
426506	4	0.0199	201.01	3	Weymouth	Pilgrim
440664	6	0.0338	177.51	4	Worcester	Gold Star

The density method was also performed for the control group (age 35-54) separately but using the same 179 roadway segments in which greater than four older drivers were involved in a crash. As with the frequency method, there were a lot more than 179 roadway segments in which greater than four drivers age 35-54 were involved in a crash but given that this research is focused upon the older driver these roadway segments were not considered.

Table 8. Age 35-55 Density Method Results – Roadway Segments

Rd Segment Id	***Age 35-55 Frequency***	***Segment Length***	***Density (per mile)***	***Rank***	***City/Town***	***Street Name***
137755	11	0.011	1000	1	Fall River	Brightman Street
426506	11	0.0199	552.76	2	Weymouth	Pilgrim Highway
440664	12	0.0338	355.03	3	Worcester	Gold Star Boulevard
77507	11	0.0499	340.68	4	Brockton	Amvets Memorial Hwy

The age 65+ rate method takes into account the traffic volume and the number of drivers involved in a crash on a particular roadway segment. It is computed by dividing the number of drivers involved in a crash on a roadway segment in a specified amount of time by the traffic volume in the specified amount of time. A multiplier of 1,000,000 was chosen to generate sufficient resolution for this analysis. The result is the number of drivers on a roadway segment per million vehicles entering the segment. The maximum average daily traffic on the 179 roadway segments of interest varies widely between individual segments. To calculate exposure the average daily traffic was multiplied by 730 days given that the time period of this data is two years. Table 9 presents the results for the age 65+ crash rate method. The top results correspond to locations which have a low average daily traffic

Table 9. Age 65+ Crash Rate Method Results – Roadway Segments

Rd Segment Id	***Age 65+ Frequency***	***Maximum ADT***	***Rate***	***Rank***	***City/Town***	***Street Name***
317554	4	100	54.795	1	Quincy	Honorable Thomas S Burgin Parkway
186618	4	200	27.397	2	Holyoke	Holyoke Street
404165	6	3000	2.740	3	Wellesley	Linden Street
404255	6	3000	2.740	3	Wellesley	Linden Street
245498	4	2000	2.740	3	Middleborough	West Grove Street

The rate method was also performed for the control group (age 35-54) separately using the same 179 roadway segments in which greater than four older drivers were involved in a crash. There were a lot more than 179 roadway segments in which greater than four drivers age 35-54 were involved in a crash but given that this research is focused upon the older driver these roadway segments were not considered.

Table 10. Age 35-55 Rate Method Results – Roadway Segments

Rd Segment Id	***Age 35-55 Frequency***	***Maximum ADT***	***Rate***	***Rank***	***City/Town***	***Street Name***
186618	12	200	82.19	1	Holyoke	Holyoke Street
317554	6	100	82.19	1	Quincy	Honorable Thomas S Burgin Parkway
300255	13	2500	7.12	2	Peabody	Summit Street
331418	8	2500	4.38	3	Salem	Loring Avenue
155628	12	4000	4.11	4	Gardner	Pearson Boulevard

The age 65+ section rate method accounts for both volume and length and is computed using the following equation:

$$Section\ Rate = \frac{(number\ drivers\ in\ crashes\ on\ the\ roadway\ segment)(100{,}000{,}000)}{(730)(ADT)(roadway\ segment\ length)}$$

The result is the number of drivers on a roadway segment per hundred million vehicle miles. The lengths and the daily vehicle count for the 179 roadway segments range significantly. These values were also multiplied by 730 days. Table 11 presents the results for the section rate method. These results are locations which either have a very low average daily traffic and/or a very small length.

Table 11. Age 65+ Section Rate Method Results – Roadway Segments

Rd Segment Id	***Age 65+ Frequency***	***Maximum ADT***	***Segment Length***	***Section Rate***	***Rank***	***City/Town***	***Street Name***
317554	4	100	0.1255	43660.97	1	Quincy	Honorable Thomas S Burgin Parkway
186618	4	200	0.1275	21488.05	2	Holyoke	Holyoke Street
102658	5	3000	0.0347	6579.55	3	Cohasset	Ripley Road
137755	4	9100	0.011	5473.98	4	Fall River	Brightman Street

The section rate method was also performed for the control group (age 35-54) separately using the same 179 roadway segments in which greater than four older drivers were involved in a crash. There were a lot more than 179 roadway segments in which greater than four drivers age 35-54 were involved in a crash but given that this research is focused upon the older driver these roadway segments were not considered.

Table 12. Age 35-55 Section Rate Method Results – Roadway Segments

Rd Segment Id	***Age 35-55 Frequency***	***Maximum ADT***	***Segment Length***	***Section Rate***	***Rank***	***City/Town***	***Street Name***
317554	6	100	0.1255	65491.46	1	Quincy	Honorable Thomas S Burgin Parkway
186618	12	200	0.1275	64464.14	2	Holyoke	Holyoke Street
137755	11	9100	0.011	15053.44	3	Fall River	Brightman Street
102658	5	3000	0.0347	6579.55	4	Cohasset	Ripley Road

Next, crash severity was taken into account using the equivalent property-damage-only method. The EPDO 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 the older driver (age 65+) age group for each of the 179 locations using the following equation:

$$\begin{aligned} EPDO\ Index = \ & (9.5)(drivers\ involved\ in\ fatal\ crashes) \\ & + (3.5)(drivers\ involved\ in\ injury\ crashes) \\ & + (1)\quad (drivers\ involved\ in\ property\ damage\ crashes) \end{aligned}$$

Table 13. Age 65+ EPDO Index Method Results – Roadway Segments

Rd Segment Id	***Property Damage***	***Injury***	***Fatal***	***Total***	***EPDO Index***	***Rank***	***City/Town***	***Street Name***
259307	3	7	0	10	27.5	1	Natick	West Central Street
427011	2	5	0	7	19.5	2	Whitman	Bedford Street
230051	1	5	0	6	18.5	3	Marshfield	Plain Street
18353	7	3	0	10	17.5	4	Attleboro	Washington Street
123201	7	3	0	10	17.5	4	East Bridgewater	Bedford Street

The severity index was computed by dividing the EPDO index by the total number of older drivers involved in a crash on each segment. The severity index seemed to bring the sites in with more serious crashes to a higher ranking (as the EPDO index method brought the roadway segments with a high frequency of older drivers involved crashes to a high ranking as it is not normalized by the number of drivers involved in crashes at the particular site).Table 14 shows the results of the age 65+ severity index method.

Table 14. Age 65+ Severity Index Method Results – Roadway Segments

Rd Segment Id	***Property Damage***	***Injury***	***Fatal***	***Total***	***EPDO Index***	***Severity Index***	***Rank***	***City/Town***	***Street Name***
440595	0	4	0	4	14	3.5	1	Worcester	Belmont Street (Route 9)
230051	1	5	0	6	18.5	3.083	2	Marshfield	Plain Street (Route 139)
323117	1	4	0	5	15	3	3	Reading	West Street
300255	1	3	0	4	11.5	2.875	4	Peabody	Summit Street
242382	1	3	0	4	11.5	2.875	4	Methuen	Pelham Street
298861	1	3	0	4	11.5	2.875	4	Peabody	Central Street
277976	1	3	0	4	11.5	2.875	4	North Adams	State Road (Route 2)
95739	1	3	0	4	11.5	2.875	4	Cheshire	South State Road (Route 8)
66502	1	3	0	4	11.5	2.875	4	Bourne	Pilgrim Highway (Route 3)

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 maximum average daily traffic on the roadway segment multiplied by 730 days (the duration of the study). A multiplier of 100,000,000 was used. Table 15 presents the results for the age 65+ EPDO rate method.

Table 15. Age 65+ EPDO Rate Method Results – Roadway Segments

Rd Segment Id	***Property Damage***	***Injury***	***Fatal***	***Total***	***EPDO Index***	***Max ADT***	***EPDO Rate***	***Rank***	***City/Town***	***Street Name***
317554	3	1	0	4	6.5	100	8904.11	1	Quincy	Honorable Thomas S Burgin Parkway
186618	4	0	0	4	4	200	2739.73	2	Holyoke	Holyoke Street
300255	1	3	0	4	11.5	2500	630.14	3	Peabody	Summit Street
242382	1	3	0	4	11.5	2900	543.22	4	Methuen	Pelham Street

Finally, the rankings of each of the seven age 65+ methods discussed above (the frequency method, density method, rate method, section rate method, EPDO index method, severity index method, and the EPDO rate method) were averaged for the 179 roadway segments to produce a new ranking. Table 16 presents the results for the age 65+ 'average of methods' method.

Table 16. Age 65+ 'Average of Methods' Method Results – Roadway Segments

Rd Segment Id	***Total***	***Rank***	***City/Town***	***Street Name***
244059	4	1	Methuen	Lowell Street (Route 114)
102658	4	2	Cohasset	Ripley Road
404165	4	3	Wellesley	Linden Street
374095	4	4	Swansea	Grand Army of the Republic Highway (Route 6)

Table 17. Older Driver HCL Summary Table – Roadway Segments

ROAD SEGMENT	City/Town	Street Name	From	To	Age 65+ Crash Frequency Method Rank	Age 35-55 Crash Frequency Method Rank	Age 65+ Crash Density Method Rank	Age 35-55 Crash Density Method Rank	Age 65+ Crash Rate Method Rank	Age 35-55 Crash Rate Method Rank	Age 65+ Section Rate Method Rank	Age 35-55 Section Rate Method Rank	Age 65+ EPDO Index Method Rank	Age 65+ Severity Index Method Rank	Age 65+ EPDO Rate Method Rank	Age 65+ Average of Methods Rank
***18353**	**Attleboro**	**Washington Street (Rt 1)**	**74.21 FT South of Cumberland Avenue**	**Como Drive**	2	3	93	28	15	7	82	26	4	12	18	32
66502	Bourne	Pilgrim Highway (Rt 3)	Ramp - Pilgrim Highway Sb to Cranberry Highway	Ramp - Cranberry Highway to Mid Cape Highway	8	20	165	144	133	138	174	168	13	4	132	143
70091	Braintree	Pilgrim Highway (Route3)	Ramp - Rt 3 Nb to Union Street	Ramp - Union Street to Rt 3 Nb	8	2	170	93	137	115	178	166	23	19	159	149
77507	Brockton	Amvets Memorial Highway	Ramp - Rt 24 Nb to Rt 27 Nb	Ramp - Route 27 Sb to Rt 24 Nb	8	12	19	4	136	134	145	72	17	9	156	114
85364	Cambridge	Mount Auburn Street	Mount Auburn Cemetery	Mount Auburn Cemetery	8	27	2	70	73	153	9	67	23	19	117	39
95739	Cheshire	South State Road (Rt 8)	Lanesboro Road	Hoosac Drive	8	28	157	174	68	159	147	174	13	4	36	99
***102658**	**Cohasset**	**Ripley Road**	**Smith Place**	**0.0347 Miles East of Smith Place**	7	23	5	11	5	12	3	4	22	19	13	2
***123201**	**East Bridgewater**	**Bedford Street (Route 18)**	**Abbey Lane**	**Whitman Street**	2	21	142	160	32	96	152	160	4	12	35	81
***137755**	**Fall River**	**Brightman Street**	**N Davol Street**	**Lindsey Street**	8	17	1	1	42	24	4	3	23	19	87	19
***155628**	**Gardner**	**Pearson Boulevard**	**Elm Street**	**Subway Entrance**	8	16	96	33	13	4	32	9	20	14	14	24
180891	Hingham	Pilgrim Highway (Route 3)	Ramp - Rt 3 Nb to Derby Street	1.1989 Miles E of Ramp - Rt 3 NB to Derby Street	3	1	168	103	130	76	177	163	13	18	152	146
186618	Holyoke	Holyoke Street	Lower Westfield Road	Mall Drive	8	16	85	26	2	1	2	2	23	19	2	9

230051	Marshfield	Plain Street (Route 139)	Old Stage Stop Vil	Fox Run	6	16	56	27	71	62	87	51	3	2	33	43
***242382**	**Methuen**	**Pelham Street**	**Aegean Drive**	**Ramp - Pelham Street to Rt 93 Sb**	8	23	135	130	8	11	37	25	13	4	4	27
244059	Methuen	Lowell Street (Route 113)	Capitol Street	0.0454 Miles North of Capitol Street	6	26	7	89	11	89	6	24	14	11	8	1
245498	Middleboro	W. Grove Street (Rt 28)	West Street	Derry Park Drive	8	25	141	156	3	15	27	44	23	19	9	34
***259307**	**Natick**	**West Central Street (Route 135)**	**Speen Street**	**Cemetery Street**	2	8	155	128	21	20	151	127	1	6	11	71
277976	North Adams	State Road (Route 2)	Chenaille Terrace	0.146 Miles East of Chenaille Terrace	8	27	97	167	87	155	108	162	13	4	53	79
***279865**	**North Andover**	**Turnpike Street (Rt 114)**	**Hillside Road**	**Mill Road**	7	2	166	73	108	22	167	113	11	8	80	131
298861	Peabody	Central Street	Water Street	Tremont Street	8	24	48	80	70	104	58	70	13	4	37	36
***300255**	**Peabody**	**Summit Street**	**Christina Drive**	**Lynnfield Street**	8	15	76	19	6	2	10	5	13	4	3	7
317554	Quincy	Honorable Thomas S Burgin Parkway	Dimmock Street	Saville Street	8	22	82	81	1	1	1	1	20	14	1	8
323117	Reading	West Street	Border Road	South Street	7	26	102	158	22	112	63	134	7	3	10	30
331418	Salem	Loring Avenue	Courageous Court	0.1011 Miles West of Courageous Court	8	20	68	40	6	3	8	8	23	19	15	10
374095	Swansea	Grand Army of the Republic Highway (Rt 6)	Swansea Mall Drive	Michael Avenue	6	26	15	124	20	128	17	79	9	9	19	4
***396861**	**Wareham**	**Cranberry Highway (Route 6)**	**Main Avenue**	**Sean Circle**	1	12	64	64	24	39	97	90	5	16	42	38
***404165**	**Wellesley**	**Linden Street**	**Donazetti Street**	**Hill Top Road**	6	24	18	69	3	21	5	12	21	19	9	3
404255	Wellesley	Linden Street	Pine Tree Road	Everett Street	6	23	101	134	3	12	20	30	21	19	9	17
426506	Weymouth	Pilgrim Highway (Route	Ramp - Rt 18 Sb to Rt 3 Sb	Ramp - Rt 3 Sb to Rt 18	8	17	3	2	137	151	118	60	20	14	158	108

		3)		Nb												
427011	Whitman	Bedford Street (Route 18)	Auburn Street	0.6731 Miles south of Auburn Street	5	16	158	140	47	55	158	145	2	5	27	91
440595	Worcester	Belmont Street (Route 9)	Edward Street	0.0604 Miles east of Edward Street	8	25	29	78	109	140	67	102	8	1	56	52
***440664**	**Worcester**	**Gold Star Boulevard (Route 12)**	**West Boylston Terrace**	**Harr Chrysler Jeep Dodge**	6	16	4	3	88	73	26	16	18	16	105	47
Total number of rankings for each method					***8***	***28***	***175***	***174***	***137***	***159***	***179***	***174***	***23***	***19***	***159***	***149***

The roadway segment IDs marked with a '*' in

Table 17 are those which were selected for a road safety investigation. These locations were chosen on the basis that they ranked in the top 5 for at least one method. At least 2 roadway segments were chosen for each method as shown in Table 18. Those which ranked in the top 5 for multiple methods were preferred to reduce the total number of investigations.

Table 18. Roadway Segments Selected for Field Investigation

HCL Existing Method	ROAD SEGMENT 1	ROAD SEGMENT 2	ROAD SEGMENT 3	ROAD SEGMENT 4
Age 65+ Crash Frequency Method Rank	123201	259307	396861	18353
Age 35-55 Crash Frequency Method Rank	279865	18353	X	X
Age 65+ Crash Density Method Rank	102658	137755	440664	X
Age 35-55 Crash Density Method Rank	137755	440664	X	X
Age 65+ Crash Rate Method Rank	102658	404165	X	X
Age 35-55 Crash Rate Method Rank	300255	155628	X	X
Age 65+ Section Rate Method Rank	102658	137755	404165	X
Age 35-55 Section Rate Method Rank	102658	137755	300255	X
Age 65+ EPDO Index Method Rank	123201	259307	369861	18353
Age 65+ Severity Index Method Rank	242382	300255	X	X
Age 65+ EPDO Rate Method Rank	242382	300255	X	X
Age 65+ Average of Methods Rank	102658	404165	X	X

Intersections

The aim is to ultimately develop a list of intersections with the potential for increased safety focused on the older driver using several existing HCL methods. The methods used include the age 65+ and age 35-55 frequency method, the age 65+ and age 35-55 spot rate method, the age 65+ EPDO index method, the age 65+ severity index method, the age 65+ EPDO rate method, and the age 65+ 'average of methods' method. This combination of methods allows for the comparison between the older driver age group (age 65+) and the control age group (age 35-54).

The high crash intersections below are presented as the Roadway Segment ID they have been assigned by the Commonwealth of Massachusetts' Office of Geographic Information. To separate the drivers involved in a crash on a roadway segment from those involved in a crash at an intersection, the "roadway intersection type" field on the Commonwealth of Massachusetts motor vehicle 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 high crash locations at intersections while drivers involved in a crash in which the "roadway intersection type" field on the crash report form indicated the crash occurred "not at junction" were included in the analysis for HCLs for roadway segments. It was thought that when a crash occurred at a particular intersection, the roadway segment ID in which it is assigned was to the roadway with the highest functional classification even if the crash actually occurred on the other intersecting roadway. This was critical in the methodology of this research as only one roadway segment ID for each intersection comprising of two or more segments must be used in identifying those intersections with a high number of older drivers involved in crashes. However, after further investigation, it seems that this is not always the case as multiple examples were identified in which a roadway segment, having multiple drivers involved in intersection crashes, was not the roadway segment within the intersection having the highest functional classification (see Data Quality Challenges for further details regarding this). As such, it is possible that more drivers were involved in crashes at the intersection than what is included in this section. It also complicates this analysis as the intersecting roadway segment of interest is not within the data but must be manually identified on a map. That is an intersection is identified by a single roadway segment ID in which multiple roadway segments may intersect, creating multiple possible intersections. All crashes are considered an intersection crash, however, using the junction field as described above. Each intersection chosen for a roadway safety investigation will be viewed extensively on a map, showing the crashes and the possible intersections. This data will be documented later in the Intersection section.

Intersections were initially identified as a HCL if a minimum of **5** older drivers were involved in a crash at an intersection linked to a roadway segment. This occurred at 386 locations for the older drivers' age group. However, it was then discovered that many of these locations occurred on an interstate at a location with an overpass or underpass and therefore were not actually at an intersection (see Data Quality Challenges for more information regarding this finding) and should therefore be removed. Additionally, it was decided that traffic circle, rotary, or roundabout locations were to be deleted as these intersections are outside of the scope of this research. Furthermore, there were some locations in which older drivers involved in intersection crashes which linked to a roadway segment occurred at more than one intersection. It was decided that for roadway segments less than or equal to 0.25 miles this was to be allowed as the intersections may influence each other and be a factor in the number of older drivers involved in a crash at that location. However, for those roadway segments greater than 0.25 miles in which the drivers involved in crashes are split between two or more intersections and in which no one intersection meets the minimum criterion of 5 older drivers being involved in a crash were removed (see Data Quality Challenges for more information regarding this finding). After the removal of the intersection locations on interstates, those at traffic circles, and those greater than 0.25 miles encompassing multiple intersections in which older drivers were involved in crashes resulted in no one intersection having a minimum of 5 older drivers in crashes were deleted, there were a total of **338** roadway segments in which a minimum of 5 older drivers were involved in a crash at a particular intersection or group of intersections within 0.25 miles of one another.

The age 65+ frequency method was based on the number of older drivers who were involved in a crash at an intersection which were linked to a particular roadway segment. A ratio was calculated for each intersection 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 intersection locations. 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 location, the majority **(91.1%)** of the 338 intersections were identified as intersection locations with an over-involvement of older drivers in crashes.

Table 19. Age 65+ Frequency Method Results – Intersections

Rd Segment Id	***Frequency 65+***	***Rank***	***City/Town***	***Street Name***	***Ratio (Older: Control)***
424843	16	1	Weymouth	Washington Street (Route 53) & Pleasant Street	1: 1.375
424934	12	2	Weymouth	Main Street (Route 18) & Middle Street & West Street	1: 1.750
375467	11	3	Taunton	Route 138 & East Britannia Street	1: 0.909
425174	11	3	Weymouth	Pleasant Street & Union Street & Columbian Street	1: 2.455

The frequency method was also performed for the control group for the 338 intersection locations. There were a lot more than 338 intersection locations but given that this research is focused on the older driver these locations were not considered.

Table 20. Age 35-55 Frequency Method Results - Intersections

Rd Segment Id	***Frequency***	***Rank***	***City/Town***	***Street Name***	***Ratio (Older: Control)***
217386	41	1	Lynn	Boston Street (Route 129) & Washington Street (Route 129)	1: 5.125
201818	38	2	Leominster	Main Street (Route 13) & Nashua Street & Hamilton Street	1: 6.333
211014	36	3	Lowell	Middlesex Street & Wood Street & Rourke Bridge	1: 7.200
424756	36	3	Weymouth	Washington Street (Route 53) & Middle Street	1: 4.500

Each of these roadways segments has a ratio of 1: > 3.87 and therefore are considered problematic roadway segments for all road users.

The spot rate method accounts for the traffic volume as well as the number 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 average daily traffic is the sum of the maximum ADT values for both intersection roadway segments (there may be 3 ADT values used for 5 point intersections). The “worst” locations correspond to locations which have a low average daily traffic.

Table 21. Age 65+ Spot Rate Method Results - Intersections

Rd Segment Id	***City/Town***	***Street Name***	***Frequency***	***Maximum ADT Total***	***Spot Rate***	***Rank***
74907	Brockton	Perkins Street & Lawrence Street	7	1200	7.991	1
229781	Marshfield	Webster Street & Snow Road	5	900	7.610	2
438516	Worcester	June Street & Hadwen Road & Brownell Street	6	2000	4.110	3
296842	Palmer	River Street & Church Street	5	1700	4.029	4

The spot rate method was also performed for the control group for the 338 intersections locations. There were a lot more than 338 intersection locations for this age group but given that this research is focused on the older driver these roadway segments were not considered.

Table 22. Age 35-55 Spot Rate Method Results - Intersections

Rd Segment Id	***City/Town***	***Street Name***	***Frequency***	***Maximum ADT Total***	***Spot Rate***	***Rank***
74907	Brockton	Perkins Street & Lawrence Street	10	1200	11.416	1
229781	Marshfield	Webster Street & Snow Road	6	900	9.132	2
74808	Brockton	West Elm Street & Ash Street	22	6000	5.023	3
440041	Worcester	Stafford Street & Curtis Parkway & Heard Street	20	5700	4.807	4

Next, crash severity was accounted for using the equivalent property-damage-only method. The EPDO 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. First, the EPDO index was computed for the older driver age group for the 338 locations using the following equation:

$$\begin{aligned} EPDO\ Index = \ & (9.5)(drivers\ involved\ in\ fatal\ crashes) \\ & + (3.5)(drivers\ involved\ in\ injury\ crashes) \\ & + (1)\quad (drivers\ involved\ in\ property\ damage\ crashes) \end{aligned}$$

Table 23. Age 65+ EPDO Index Method Results - Intersections

Rd Segment Id	***City/Town***	***Street Name***	***Property Damage***	***Injury***	***Fatal***	***Total***	***EPDO Index***	***Rank***
375467	Taunton	Route 138 & East Britannia Street	2	9	0	11	33.5	1
111764	Dedham	Washington Street & Elm Street	2	8	0	10	30	2
348139	Somerset	Route 6 & Lees River Avenue	1	7	0	8	25.5	3
424843	Weymouth	Washington Street (Route 53) & Pleasant Street	13	3	0	16	23.5	4

Next, the severity index was computed by dividing the EPDO index for each intersection location by the total number of older drivers involved in crashes at the location. The severity index seemed to bring the sites in which a fatal crash occurred to a higher ranking. There were only a few drivers in fatal crashes within these 338 intersection locations.

Table 24. Age 65+ Severity Index Method Results - Intersections

Rd Segment Id	***City/Town***	***Street Name***	***Property Damage***	***Injury***	***Fatal***	***Total***	***EPDO Index***	***Severity Index***	***Rank***
240175	Melrose	Lebanon Street & Malvern Street	0	5	0	5	17.5	3.5	1
135731	Fall River	Hanover Street & New Boston Road	3	2	1	6	19.5	3.25	2
135636	Fall River	President Avenue (Route 6) & Robeson Street	3	1	1	5	16	3.2	3
307749	Plainville	Washington Street (Route 1) & Everett Skinner Road	3	1	1	5	16	3.2	3

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 maximum average daily traffic for both roadways in the intersection multiplied by 730 days (the duration of the study). A multiplier of 100,000,000 was used for better resolution.

Table 25. Age 65+ EPDO Rate Method Results – Intersections

Rd Segment Id	***City/Town***	***Street Name***	***Age 65+ freq.***	***EPDO Index***	***Max ADT***	***EPDO Rate***	***Rank***
74907	Brockton	Perkins Street & Lawrence Street	7	14.5	1200	1655.25	1
229781	Marshfield	Webster Street & Snow Road	5	7.5	900	1141.55	2
296842	Palmer	River Street & Church Street	5	10	1700	805.80	3
394139	Ware	Pleasant Street & North Street	6	16	4000	547.95	4

Finally, the rankings of each of the 5 age 65+ methods discussed above (the frequency method, spot rate method, EPDO index method, severity index method, and the EPDO rate method) were averaged for the 338 intersections to produce a new ranking.

Table 26. Age 65+ ‘Average of Methods’ Method Results - Intersections

Rd Segment Id	***City/Town***	***Street Name***	***Age 65+ freq.***	***Rank***
97032	Chicopee	Arcade Street & McKinstry Avenue	8	1
394139	Ware	Pleasant Street & North Street	6	2
74907	Brockton	Perkins Street & Lawrence Street	7	3
375467	Taunton	Route 138 & East Britannia Street	11	4

Table 27. Older Driver HCL Summary Table – Intersection

Road Segment	City/Town	Street Name	Age 65+ Frequency Method Ranking	Age 35-55 Frequency Method Ranking	Age 65+ Spot Rate Method Ranking	Age 35-55 Spot Rate Method Ranking	Age 65+ EPDO Index Method Ranking	Age 65+ Severity Index Method Ranking	Age 65+ EPDO Rate Method Ranking	Age 65+ Average of Methods Ranking
***424843**	**Weymouth**	**Washington Street (Route 53) & Pleasant Street**	1	14	22	35	4	26	41	22
424934	Weymouth	Main Street (Route 18) & Middle Street & West Street	2	15	96	127	10	24	129	91
***375467**	**Taunton**	**Route 138 & East Britannia Street**	3	26	27	93	1	7	12	4
425174	Weymouth	Pleasant Street & Union Street & Columbian Street	3	9	39	26	17	27	76	57
***217386**	**Lynn**	**Boston Street (Route 129) & Washington Street (Route 129)**	6	1	84	17	27	30	152	108
***201818**	**Leominster**	**Main Street (Route 13) & Nashua Street & Hamilton Street**	8	2	195	38	34	33	282	228
211014	Lowell	Middlesex Street & Wood Street & Rourke Bridge	9	3	249	55	35	33	303	251
424756	Weymouth	Washington Street (Route 53) & Middle Street	6	3	64	12	22	24	96	77
***74907**	**Brockton**	**Perkins Street & Lawrence Street**	7	26	1	1	20	18	1	3
***229781**	**Marshfield**	**Webster Street & Snow Road**	9	30	2	2	32	25	2	10
438516	Worcester	June Street & Hadwen	8	35	3	168	34	33	7	16

		Road & Brownell Street								
296842	Palmer	River Street & Church Street	9	31	4	8	28	19	3	8
74808	Brockton	West Elm Street & Ash Street &	9	14	26	3	28	19	31	29
440041	Worcester	Stafford Street & Curtis Parkway & Heard Street	6	16	8	4	22	24	14	11
111764	Dedham	Washington Street & Elm Street	4	26	45	130	2	8	26	16
***348139**	**Somerset**	**Route 6 & Lees River Avenue**	6	16	79	59	3	4	52	46
240175	Melrose	Lebanon Street & Malvern Street	9	33	46	220	14	1	19	19
***135731**	**Fall River**	**Hanover Street & New Boston Road**	8	28	28	53	10	2	11	6
135636	Fall River	President Avenue (Route 6) & Robeson Street	9	18	201	105	17	3	121	129
***307749**	**Plainville**	**Washington Street (Route 1) & Everett Skinner Road**	9	27	204	222	17	3	123	132
394139	Ware	Pleasant Street & North Street	8	35	6	252	17	10	4	2
***97032**	**Chicopee**	**Arcade Street & McKinstry Avenue**	6	30	14	67	5	9	5	1
Total Number of Rankings for Each Method			***9***	***36***	***267***	***303***	***35***	***33***	***308***	***257***

Table 27 are those which were selected for a road safety investigation. These locations were chosen on the basis that they ranked in the top 5 for at least one method. At least 2 roadway segments were chosen for each method as shown in Table 28. Those which ranked in the top 5 for multiple methods were preferred to reduce the total number of investigations.

Table 28. Intersections Selected for Field Investigations

HCL Existing Method	**ROAD SEGMENT 1**	**ROAD SEGMENT 2**	**ROAD SEGMENT 3**	**ROAD SEGMENT 4**
Age 65+ Frequency Method	375467	424843	x	x
Age 35-55 Frequency Method	217386	201818	x	x
Age 65+ Spot Rate Method	74907	229781	x	x
Age 35-55 Spot Rate Method	74907	229781	x	x
Age 65+ EPDO Index Method	348139	375467	424843	97032
Age 65+ Severity Index Method	348139	135731	307749	x
Age 65+ EPDO Rate Method	74907	229781	97032	x
Age 65+ Average of Methods	74907	375467	97032	x

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 (the rankings do not need to match for each method).

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 density method are generally those with the smallest roadway segments, 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 same holds for the rate method as those with very small average daily traffic numbers rank among the highest. Although the rate methods may seem best suited for identifying dangerous locations as it takes into account exposure, caution must be used when relying on this method alone as the Massachusetts data for the average daily traffic is regarded as poor quality and may not be reliable or accurate in many instances. The results of the density method and the rate method often correlate with the section rate method as the segment size and average daily traffic are utilized; however, the results generally only correlated to one method or the other. The rate method also somewhat correlated to the EPDO rate method as the average daily traffic is also 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.

Figure 14 below shows the pinpointed locations which were chosen for field safety investigations. The blue markers represent the roadway segment locations while the green markers represent the intersection locations.

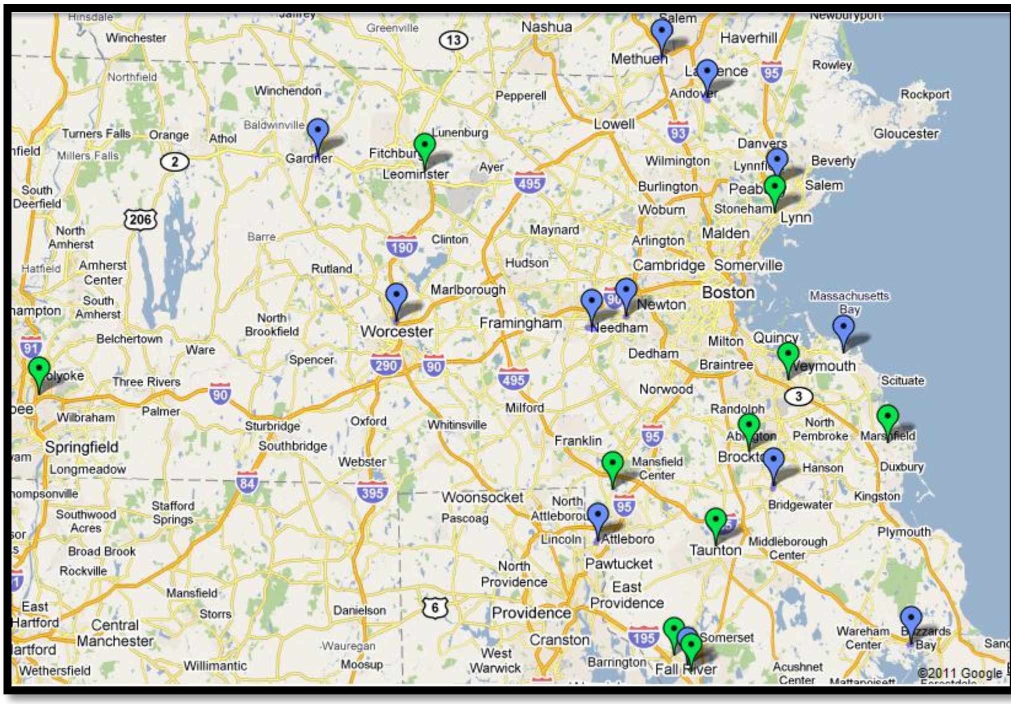


Figure 14. Map of Locations Chosen for Field Safety Investigations

The challenges these locations pose to older drivers will only amplify if countermeasures are not implemented to better accommodate older drivers at these locations. Figure 15 shows the towns in which the roadway segments resulting from this spatial analysis (as presented in

Table 17) are located (highlighted in red) and the towns in which the intersections resulting from this spatial analysis (as shown in

Table 27) are located (highlighted in black) in conjunction with the corresponding population change projected from 2000 to 2020. As shown, many of these towns will see a large increase in older residents.

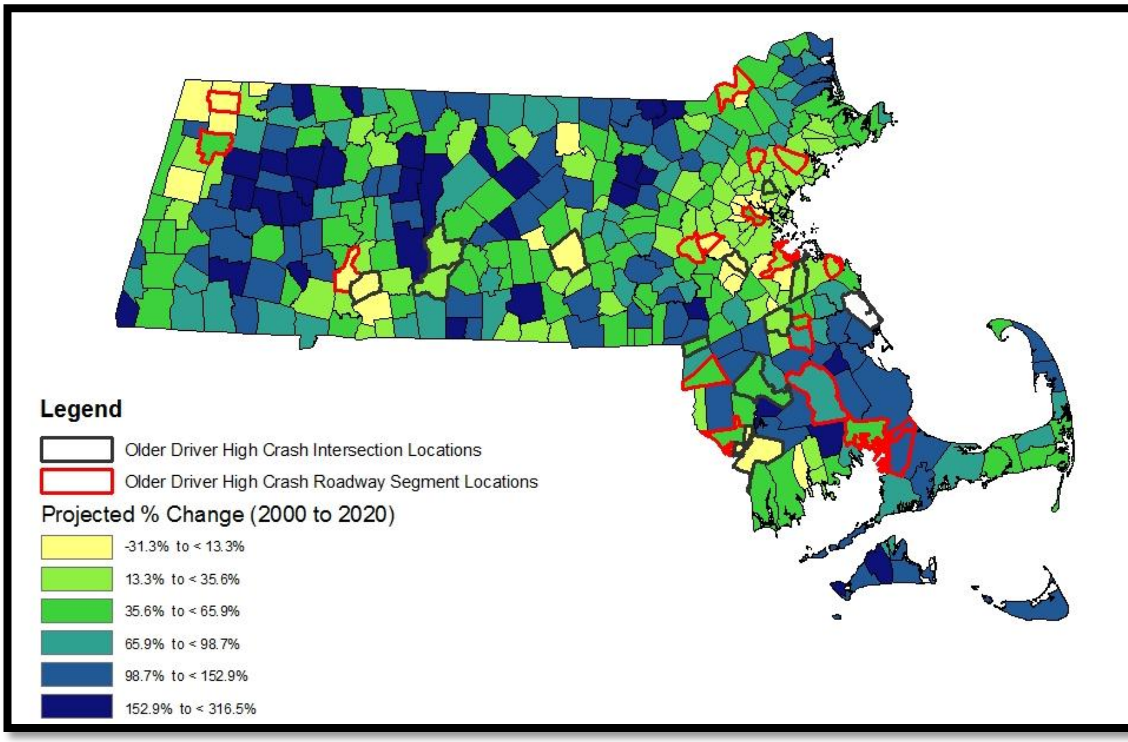


Figure 15. Projected Percent Change in Massachusetts Population Age 65+ by Town (2000-2020)

Data Quality Challenges

This research was limited to the crash data available for the Commonwealth of Massachusetts (see Research Scope for more information regarding this). 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. In this analysis, it is imperative that the crash can be geo-located based on the information presented on the crash report form. Furthermore, drivers involved in a crash in which the "roadway intersection type" field on the crash report form was reported as unknown or was invalid or empty had to be removed from this data set. Although these conditions reduce the sample size for this analysis, the sample remains large and will provide an accurate sense of intersections and roadway segments which are posing challenges for older drivers.

The research was also limited to the data available in the roadway inventory file from the Massachusetts Department of Transportation and the unique identifiers within the data sets which could allow for the roadway inventory file and the crash data to be successfully joined. The unique identifier within the roadway inventory file is the roadway inventory id, while the crash data could only be identified in terms of the roadway segment id, which is not as precise as the roadway inventory id (in many cases a roadway segment encompasses several roadway inventories). As a result, choices had to be made to create a data set which balanced both quantity and accuracy. Many fields within the roadway inventory file could not be used as it was not clear which roadway inventory id the crash actually occurred. Since it was critical to this research that crash rates could be computed, the ADT field was used. It was decided that the roadway inventory id with the highest ADT value would be chosen as the ADT value to represent the entire roadway segment. Furthermore, the lengths of each roadway inventory id for a roadway segment were added to compute the roadway length at the roadway segment id level.

Caution still had to be used when using the ADT data as the Massachusetts data for the average daily traffic is regarded as poor quality and may not be reliable or accurate in many instances. In instances where the ADT was 0 vehicles per day for a roadway segment within the data or for the intersecting roadway when identifying HCL intersections, the site was deleted from the data set altogether. In some instances it seemed as though the ADT was an underestimate. This was the reason that roadway segment 317554 in Quincy, Massachusetts which had an ADT of 100 vehicles per day and roadway segment 186618 in Holyoke, Massachusetts which had an ADT of 200 vehicles per day were not selected as sites for a road safety investigation even though they ranked highly using several methods. These ADT values seemed very unrealistic and these locations repeatedly ranked high in methods using these values.

There were further data quality issues which arose when conducting the intersection HCL analysis. It was originally thought that when a crash occurred at a particular intersection, the roadway segment ID in which it is assigned was to the roadway with the highest functional classification even if the crash actually occurred on the other intersecting roadway. This was critical in this analysis as only one roadway segment ID for each intersection comprising of two or more roadway segments could be used to identifying the ODHCL's as there is no way to know which roadway segments intersect without manually zooming to each location in Arc GIS. However, after further investigation, it seems that this is not always the case as multiple examples were identified in which a roadway segment, having multiple drivers involved in intersection crashes, was not the roadway segment within the intersection having the highest functional classification. For example, Figure 16 shows roadway segment 135636 highlighted in light blue, which is on Robeson Street in Fall River, Massachusetts. The crashes at this intersection, represented by a small light blue dot, snapped to this roadway segment even though the intersecting roadway segment is Route 6, a major arterial roadway. Crashes could have snapped to the roadway segment ids on the approaches to this intersection on Route 6, but unless a minimum of 5 did so, these would not appear within the data set.

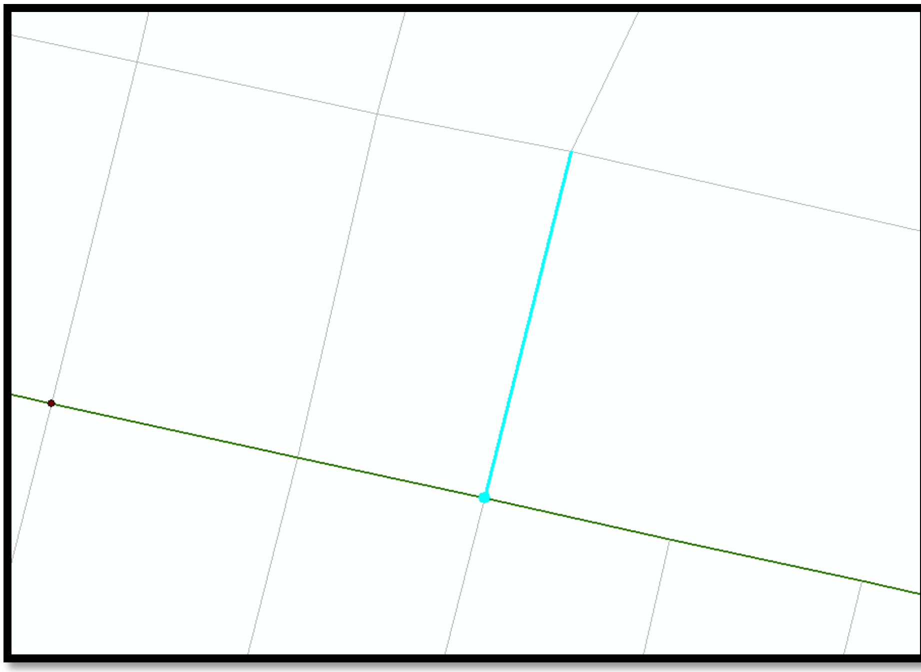


Figure 16. Roadway Segment 135636 Robeson Street Fall River

As such, it is possible that more drivers were involved in crashes at the intersection than what is included in this analysis in the Identifying ODHCL’s and Intersection Road Safety Investigations sections of this paper and it is therefore important to realize that more crashes may have occurred than what it presented. It also complicates this analysis as the intersecting roadway segment of interest is not within the data but must be manually identified on a map, in order to identify the ADT for the intersecting roadway and to confirm that the roadway segment identified is in fact the highest for that roadway, i.e. the segment across from the identified segment could have a higher ADT value. It still holds, however, that these locations are HCLs, as they meet the minimum criterion. Furthermore, the ability to improve the intersection locations to better accommodate the older driving population is still desirable.

Also discovered when conducting the HCL intersection analysis is that an intersection identified because greater than or equal to 5 older drivers were involved in an intersection crash linked to a single roadway segment ID does not mean that all the crashes necessarily occurred at the same intersection, i.e., there were some locations in which the older drivers were involved in intersection crashes on a roadway segment but at more than one intersection. This was concerning as the location may then not be of interest if no one intersection had a minimum of 5 drivers involved in crashes as this number was split between two intersections, one at each end of the roadway segment. It was decided that for roadway segments less than or equal to 0.25 miles this was to be allowed as the intersections may influence each other and be a factor in the number of older drivers involved in a crash. However, for those roadway segments greater than 0.25 miles whose crashes are split between two or more intersections and no one intersection meets the minimum criterion of 5 older drivers involved in a crash should be removed. There were only 25 locations in which the segment length was greater than 0.25 miles, resulting in only a few locations being deleted for this reason.

Many of the intersection HCLs occurred on interstates at the intersection of an overpass or underpass. Seemingly, the officer decided that it would most effective to identify the crash location, which presumably occurred in close proximity to the overpass or underpass (perhaps at the on ramp or off ramp where officers generally have trouble accurately identifying a crash on the crash report form as it is unclear to them what the appropriate technique to do so is) using the ‘at intersection’ part of the crash report form. Although this may make sense in some regards, it complicates and increases the chance for error in this sort of data analysis as one has to manually go through the locations to remove those which occurred at the ‘intersection’ of an interstate and another roadway with an overpass or underpass. This same issue would make it extremely difficult to pinpoint specific on ramps or off ramps with a high number of crashes.

One major data quality finding was the reality of what crashes which occurred ‘not at intersection’ actually means. This separation was initially taken in an attempt to separate crashes which occurred at an unsafe intersection from those which occurred on an unsafe horizontal or vertical curve or segment as older drivers have been known to have particular difficulty at such locations and the *Older Driver Highway Design Handbook* separates such locations accordingly. It was discovered, however, that many crashes which occurred on a roadway segment actually occurred at an intersection but were identified by the officer at the scene of the crash as ‘not at intersection’. In many cases this is most likely due to the fact that many of these crashes occurred at the intersection of roadway and a driveway to a store or business. There is a ‘driveway’ field that the officer may use when filling out the crash report form, which was included in the ‘at intersection’ locations, however, this field is rarely used. As a result many of the high crash roadway segments identified are segments with many driveways in close proximity to each other and a lot going on for the driver to look at. Although this was not originally expected, this finding is still notable, and the resulting roadway segments identified still have an over-involvement older drivers involved in crashes and should therefore, still for looked at for countermeasures to aid in reducing the number older drivers involved in crashes at these locations.

Conversely, there are some very short roadway segments which ranked highly in the density method calculations which turn out to actually just encompass one intersection. It is unclear as to why the officer recorded these crashes as ‘not at intersection’. Perhaps future research should attempt to combine the analyses of intersection and roadway segment crashes or alternative ways make this distinction should be explored. It is concerning that crash numbers identified are not accurate as more crashes may have occurred at these HCL’s which are within the other data set, i.e., drivers involved in intersection crashes at the HCL’s were recorded as ‘not at intersection’ and are therefore in the other data set and ignored it this analysis or vice versa. That being said, these locations still met the minimum criterion of 5 older drivers involved in crashes for the intersection locations and at least 4 older drivers involved in crashes for the roadway segments in 2007 and 2008 and are therefore are still considered HCLs with the potential to better accommodate older drivers and thus are worth looking at further.

There was one location (intersection 229781 – the intersection of Webster Street & Snow Road in Marshfield, Massachusetts) in which it appears as though significant changes and major improvements have been made which are not yet updated in the EOT_MAJOR ROADS file or in map view in Google maps which were utilized in this project. The satellite view in Google maps does seem to be updated, however. The road which is displayed in GIS has been closed and Snow Road now runs further south to connect with Library Plaza (see Field Safety Review section). This may be to new development including a Marshalls and many other stores in this area which can now be easily accessed by using Snow Road. It is noteworthy, however, that these improvements are such that would have been recommended through this research and that this location will now better accommodate older drivers.

Intersection Road Safety Investigations

Intersection 74907 is the intersection of Perkins Street & Lawrence Street in Brockton, Massachusetts. It has an estimated total ADT of 1,200 vehicles per day. In 2007 and 2008, there were a total of **7 drivers age 65+ and 10 drivers between the ages of 35-55** involved in crashes at this intersection. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes at this intersection is less than the statewide ratio of 1:3.87, this location has been identified as a location in which older drivers are overrepresented in crashes. 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 be conducted as it ranked **1st out of 267 for the age 65+ spot rate method**, **1st out of 303 for the age 35-55 spot rate method**, **1st out of 308 for the age 65+ EPDO rate method**, and **3rd out of 257 for the age 65+ 'average of methods' method**.

Figure 17. Intersection 74907 Google Map

The intersection of Perkins Street & Lawrence Street in Brockton, Massachusetts is a four-way intersection with 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 right as you approach the stop sign. There are not crosswalks at this location and no indications of a bus stop (although Google maps indicate that the

Brockton Area Transit Authority stops at this intersection). Higher speeds along mainline may also 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. It seems that this location may better accommodate older drivers if this recommendation 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, as shown in Figure 18 in red. Perhaps a flashing red signal could be installed. 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*.

Figure 18. Intersection 74907 Satellite View with Relocated Stop Bars

Figure 19. Intersection 74907 Photos

<u>Intersection 229781</u> is the intersection of Webster Street & Snow Road in Marshfield, Massachusetts. It has an estimated total ADT of 900 vehicles per day. In 2007 and 2008, there were a total of **5 drivers age 65+ and 6 drivers between the ages of 35-55** involved in crashes at this intersection. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes at this intersection is less than the statewide ratio of 1:3.87, this location has been identified as a location in which older drivers are overrepresented in crashes. Of the 5 older drivers involved in crashes at this intersection, 4 older drivers were involved in 2 vehicle crashes and 1 older driver was involved in a 3 vehicle crash. All 5 older drivers involved in crashes at this intersection were involved in angle crashes. The driver contributing code on the crash report form indicates that 2 drivers failed to yield right of way. It should also be noted that 4 drivers were involved in property damage only crashes and 1 driver was involved in a non-fatal injury crash. This intersection was chosen as a location in which a road safety investigation be conducted as it ranked **2nd out of 267 for the age 65+ spot rate method**, **2nd out of 303 for the age 35-55 spot rate method**, and **2nd out of 308 for the age 65+ EPDO rate method**.

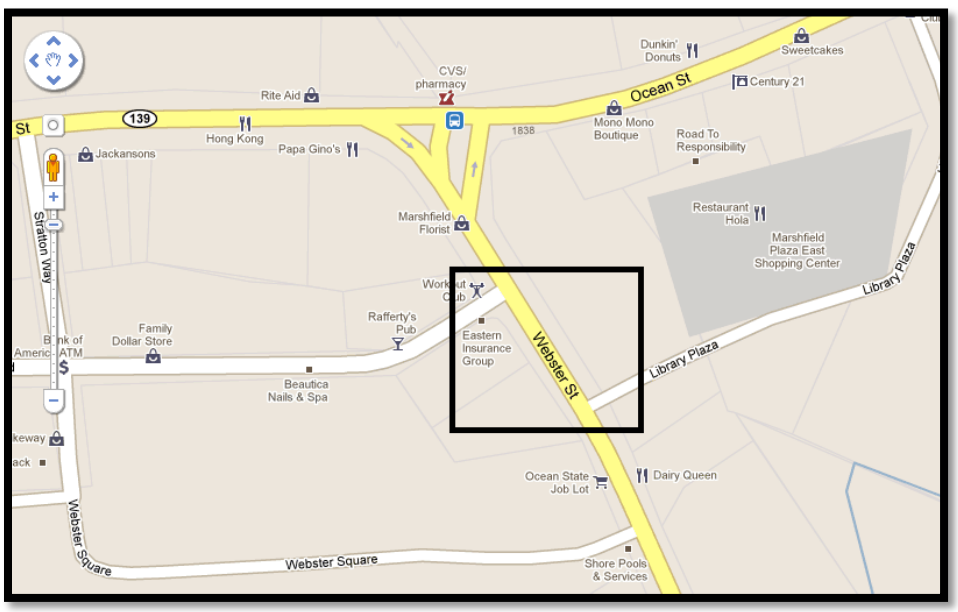


Figure 20. Intersection 229781 Google Map

The intersection of Webster Road & Snow Road in Marshfield, Massachusetts is a four-way intersection stop-controlled on the minor roadways (Snow Road & Library Plaza). It appears as though major improvements have been made since at these areas which are not yet updated in the EOT_MAJOR ROADS file or in map view in Google maps which were utilized in this project. The road which is shown above has been closed and Snow Road now runs further south to connect with Library Plaza. This may be because of a new development, including a Marshalls and many other stores, in this area which can now be easily accessed by using Snow Road. With the reconfiguration of this intersection it appears that many improvements which will better accommodate older drivers have been implemented including new signage, pavement markings, an island, and highly visible crosswalks. In conjunction the intersection is now set further back from the intersection of Ocean Street & Webster Street and Snow Road and Library Plaza align with one another. It seems as though the ADT within the data for Snow Road may be inaccurate (see Data Quality Challenges section). It is clear that the previous location of Snow Road would have had sight restrictions and would have been in very close proximity to the major intersection of Ocean Street & Webster Street. Although these improvements have been made to this area, it remains a busy with a lot going on and a lot to look at. Perhaps a flashing red light could be installed on Snow Road and/or a flashing yellow signal on Webster Street. Additionally, a supplemental warning sign panel mounted below the STOP sign reading “CROSS TRAFFIC DOES NOT STOP” could be included to better accommodate older drivers. As is the case with many locations especially after the winter months, the pavement markings are fading and should be repainted.

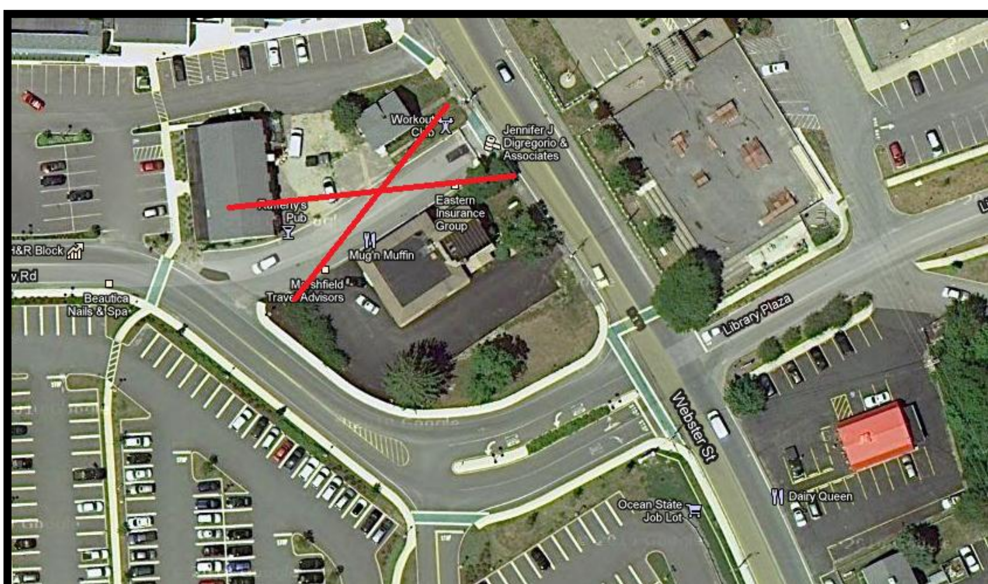


Figure 21. Intersection 229781 Satellite View Showing Roadway Closure

Intersection 348139 is the intersection of Route 6 & Lees River Avenue in Somerset, Massachusetts. It has an estimated total ADT of 19,700 vehicles per day. In 2007 and 2008, there were a total of **8 drivers age 65+ and 20 drivers between the ages of 35-55** involved in crashes at this intersection. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes at this intersection is less than the statewide ratio of 1:3.87, this location has been identified as a location in which older drivers are overrepresented in crashes. 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 be conducted as it ranked **3rd out of 35 for the age 65+ EPDO Index method** and **4th out of 33 for the age 65+ severity index method**.

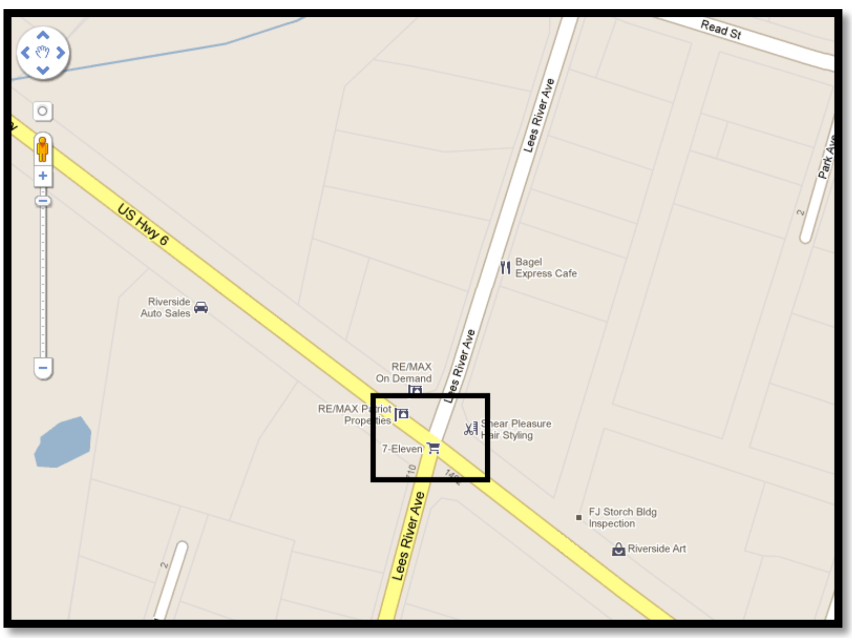


Figure 22. Intersection 348139 Google Map

The intersection of Route 6 & Lees River Avenue in Somerset, MA is a four-way signalized intersection. The 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. It does seem that right of way restrictions would 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 should be implemented overhead. 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. 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 the 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 such as this intersection 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.

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.

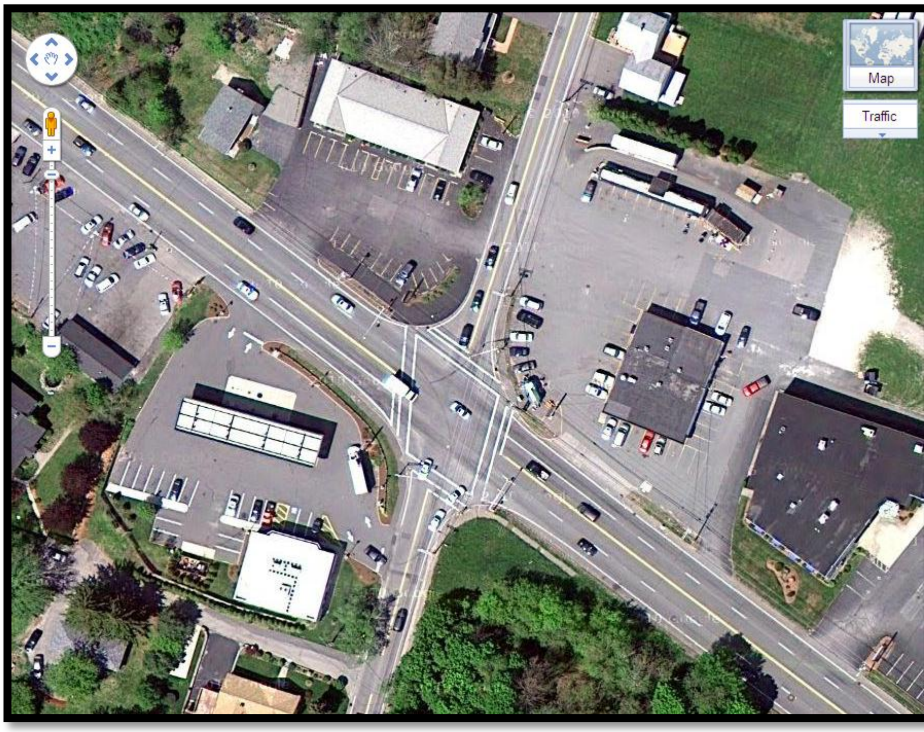


Figure 23. Intersection 348139 Satellite View Showing Skewed Geometry

Figure 24. Intersection 348139 - Solar Glare

Figure 25. Intersection 348139 – Large Intersection Size

Intersection 135731 is the intersection of Hanover Street & New Boston Road in Fall River, Massachusetts. It has a total maximum ADT of 7,600 vehicles per day. In 2007 and 2008, there were a total of **6 drivers age 65+ and 8 drivers between the ages of 35-55** involved in crashes at this intersection. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes on this segment is less than the statewide ratio of 1:3.87, this location has been identified as a location in which older drivers are overrepresented in crashes. Of the 6 older drivers involved in crashes at this intersection, 5 drivers were involved in 2 vehicle crashes while 1 driver was involved in a 3 vehicle crash. Furthermore, 4 drivers were involved in angle crashes and one driver was involved in a head-on collision (the 6th driver manner of collision is unknown). The driver contributing code on the crash report form indicates that 4 drivers disregarded signals, signs, and markings and one driver was faulted for driving on the wrong side or wrong way. It should also be noted that 3 drivers were involved in property damage only crashes while 2 drivers were involved in non-fatal injury crashes, and **1 driver was involved in a fatal crash**. This intersection was chosen as a location in which a road safety investigation be conducted as it ranked **2nd out of 33 for the age 65+ severity index method**.

Figure 26. Intersection 135731 Google Map

The intersection of Hanover Street & New Boston Road in Fall River, Massachusetts is a very confusing intersection as both sides of Hanover Street are one way but in opposite directions from New Boston Road. Furthermore, motorists drive around the blind curve on New Boston Road at relatively high speeds and quickly approach this interaction. Sigh distance due to buildings in close proximity to the intersection could also be a potential issue. Additionally, the road conditions are poor at this intersection. There is clear pedestrian activity at this intersection including a bus stop at the intersection and a hospital in very close proximity. Given that 5 of the 6 older drivers involved in crashes at this intersection were faulted for either disregarding signals, signs, and markings or for driving on the wrong side or wrong way, it is clear that this intersection is confusing. The best solution would be to eliminate this one way in opposite directions scenario at this intersection. If this is not feasible, better signage could be implemented including “DO NOT ENTER” or “WRONG WAY” signs on the one way roadways or at intersections in close proximity to this intersection as this must be the root of the program since it is impossible to go the wrong way at this intersection (the driver must have already been traveling the wrong way). Also a yellow warning sign could be used on New Boston Road to aware drivers that that roadway is a two way roadway. Similarly, stop signs or yield sings might help so that drivers are required to stop, giving more opportunity to think about which direction they are about to travel and realize that this is indeed an intersection.

Pavement markings in the form of arrows may also be useful to make it clear to the drivers that these are one way roadways. The roads should be repaved and repainted and better accommodations could be given to pedestrians. A larger bus stop sign could be beneficial. Furthermore, a warning sign indicating a curve may be helpful. The most dangerous scenario at this intersection seems to be when a vehicle is traveling at relatively high speed around the corner and not noticing that a vehicle is taking a left turn onto Hanover Street. Perhaps a flashing yellow beacon could be beneficial. An easy and helpful solution may be to relocate the one way signs as they do not seem to be placed optimally in relation to the pedestrian warning signs. However, when traveling in the right direction of any approach it is impossible to make a wrong turn, indicating that the root of this problem is elsewhere.

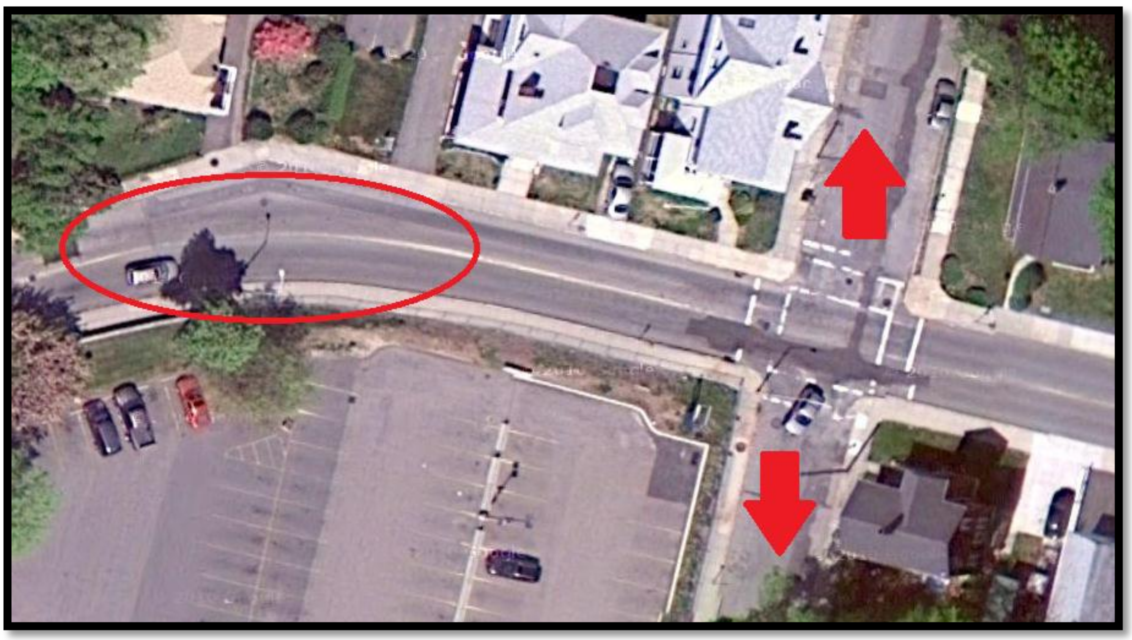


Figure 27. Intersection 135731 Satellite View Showing One Way Scenario

Figure 28. Intersection 135731 Showing One Way Sign Location

Intersection 375467 is the intersection of Route 138 & East Britannia Street in Taunton, Massachusetts. It has a total maximum ADT of 13,309 vehicles per day. In 2007 and 2008, there were a total of **11 drivers age 65+ and 10 drivers between the ages of 35-55** involved in crashes at this intersection. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes on this segment is less than the statewide ratio of 1:3.87, this location has been identified as a location in which older drivers are overrepresented in crashes. 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 age 65+ EPDO index method, 3rd out of 9 for the age 65+ frequency method, and 4th out of 257 for the age 65+ 'average of methods' method**.

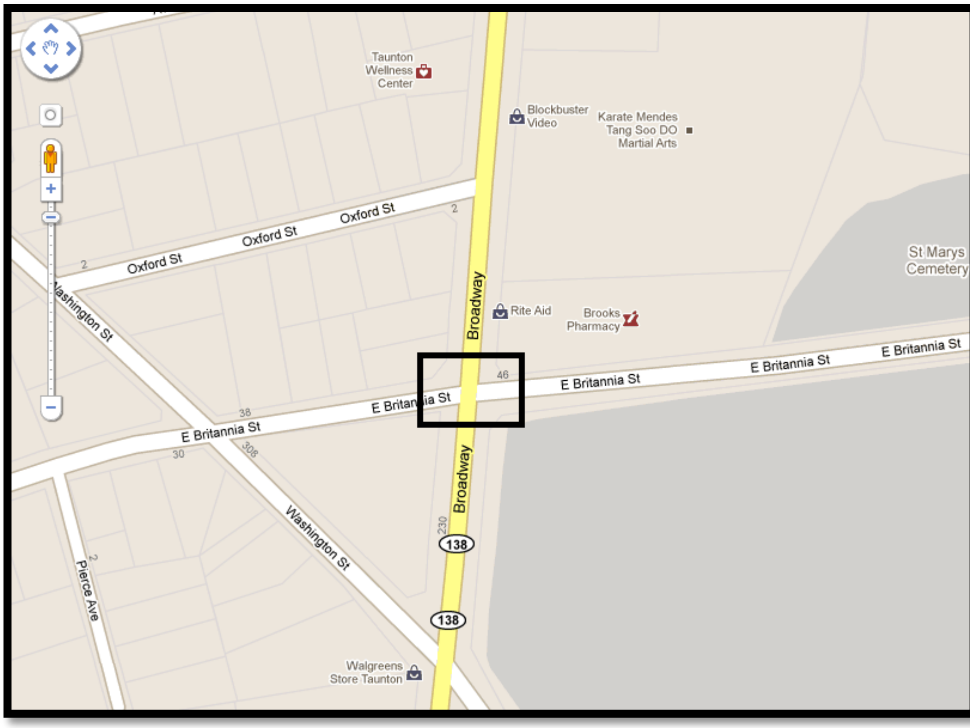


Figure 29. Intersection 375467 Google Map

The intersection of Route 138 & East Britannia Street in Taunton, Massachusetts 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 30. Intersection 375467 Satellite View

Figure 31. Intersection 375467 – Location of NO TURN ON RED Sign

Intersection 424843 is the intersection of Washington Street (Route 53) & Pleasant Street in Weymouth, Massachusetts. It has a total maximum ADT of 16,400 vehicles per day. In 2007 and 2008, there were a total of **16 drivers age 65+ and 22 drivers between the ages of 35-55** involved in crashes at this intersection. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes on this segment is less than the statewide ratio of 1:3.87, this location has been identified as a location in which older drivers are overrepresented in crashes. Of the 16 older drivers involved in crashes at this intersection, 15 drivers were involved in 2 vehicle crashes and 1 driver was involved in a 3 vehicle crash. Furthermore, 12 drivers were involved in angle crashes, 2 drivers were involved in rear-end crashes, and 2 drivers were involved in sideswipe same direction crashes. The driver contributing code on the crash report form indicates that 3 drivers disregarded signals, signs, and markings, one driver followed too closely, one driver made an improper turn, one driver drove too fast for conditions, and one driver failed to yield right of way. It should also be noted that 13 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 be conducted as it ranked **1st out of 9 for the age 65+ frequency method and 4th out of 35 for the age 65+ EPDO index method.**

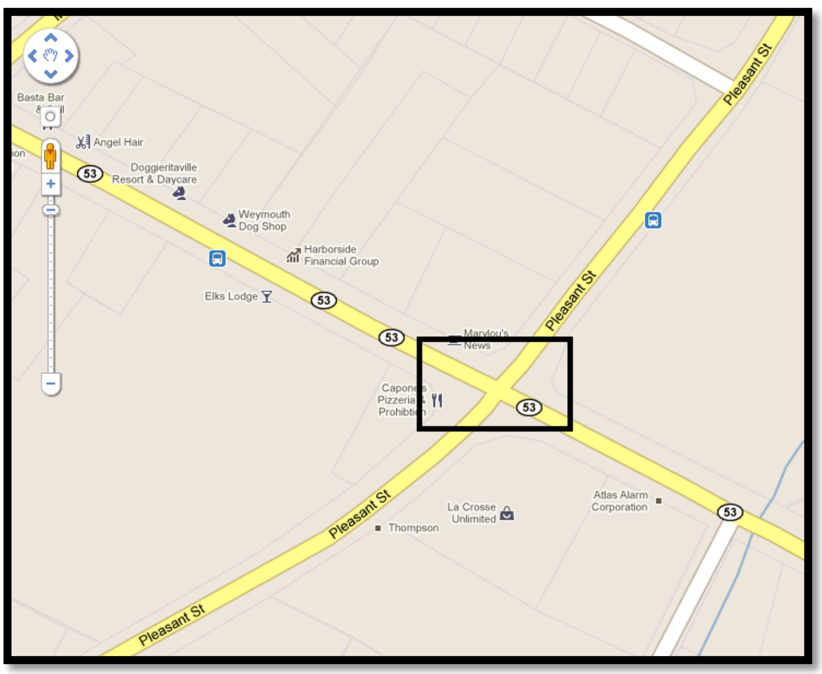


Figure 32. Intersection 424843 Google Map

The intersection of Washington Street (Route 53) & Pleasant Street in Weymouth, Massachusetts is a four-way signalized intersection. It is relatively high speed and volume on both roadways with driveways in close proximity to the intersection. One of the small plazas near this intersection (on the northwest side) has a very small and hardly noticeable “RIGHT TURN ONLY” sign but perhaps this could be made more clear and be implemented at other locations surrounding the intersection. Buildings are also located in close proximity to the intersection, potentially obstructing motorist's sight distance, especially on the southwest side. Pleasant Street also seems to be an uphill grade when approaching the intersection from the North, at-grade at the intersection, and a downhill grade heading south after passing through the intersection, causing possible sightline restrictions as you may not be able to see a vehicle coming over the hill when taking a left turn onto Route 53 from the North. The intersection is large in nature as Route 53 is a four lane roadway and Pleasant Street is a two lane roadway. There are no dedicated turn lanes. It appears that a protected left turn phase in conjunction with dedicated left turn lanes would be beneficial on Route 53 and possibly on Pleasant Street 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 Handbook* 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. It does seem that right of way restrictions would be an issue at this location and an unacceptable decline in capacity would result from the removal of a through lane. As such, the addition of signage indicating to motorists that they must yield to through traffic when taking a left turn should be implemented above the intersection. Pavement markings which scribe a path through the turn may also be beneficial at this location. This intersection is currently slightly 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 probable right of way restrictions, this change may not be feasible. Given that these roadways are major roadways with relatively high speeds, no right turn on red is a strategy which could better accommodate older drivers. 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, the posting of signs with the legend "TURNING TRAFFIC MUST YIELD TO PEDESTRIANS" should be implemented. The crosswalks are hardly noticeable and should be repainted as should be the centerline and edge lines for clearer lane delineation as it is somewhat unclear as to how many lanes are actually present. Furthermore, the crosswalks should be horizontal rather than at an angle. There is currently a warning sign indicating that a signal is ahead on one approach that was noticed. Perhaps these signs could be implemented more often in conjunction with other traffic calming measures, especially on Pleasant Street. 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 33. Intersection 424843 Satellite View

Figure 34. Intersection 424843 – RIGHT TURN ONLY Sign and Solar Glare

Intersection 217386 is the intersection of Boston Street (Route 129) & Washington Street (Route 129) in Lynn, Massachusetts. It has an estimated total ADT of 20,300 vehicles per day. In 2007 and 2008, there were a total of **8 drivers age 65+ and 41 drivers between the ages of 35-55** involved in crashes at this intersection. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes at this intersection is greater than the statewide ratio of 1:3.87, this location has been identified as a high crash location for all age groups. Of the 8 older drivers involved in crashes at this intersection, 7 drivers were involved in 2 vehicle crashes and 1 driver was involved in a 3 vehicle crash. Furthermore, 4 drivers were involved in angle crashes while 1 driver was involved in a sideswipe same direction crash, 2 drivers were involved in rear-end crashes, and 1 drive was involved in a head-on collision. The driver contributing code on the crash report form indicates that 2 drivers disregarded traffic signs, signals, or markings, 1 driver made an improper turn, 1 driver failed to yield right of way, and 1 driver was not paying attention. It should also be noted that 7 drivers were involved in property damage only crashes while 1 driver was involved in non-fatal injury crash. This intersection was chosen as a location in which a road safety investigation be conducted as it ranked **1st out of 36 for the age 35-55 frequency method.**

Figure 35. Intersection 217386 Google Map

The intersection of Boston Street (Route 129) & Washington Street (Route 129) in Lynn, Massachusetts is a high volume; high speed t-intersection in which the major route (Route 129) requires a left turn movement when traveling southbound. This area is very busy as it is in close proximity to many businesses including a Super Stop and Shop, the Bay Ridge Hospital, and a very large cemetery. There are dedicated left turn lanes, with the appropriate signage at this location "LEFT TURN YEILD ON GREEN". There appears to be sightline issues. First, solar glare seems to be an issue, possibly making it unclear of which signal indication is on. Furthermore, signs for the corner gas station as well as the Stop & Shop in conjunction with the skewed geometry of the intersection make for a situation in which the driver must take a left turn without being able to see what is ahead of them until they have already made the turn. 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, this change may not be feasible. However, signage could be changed and better measures to reduce solar glare could be implemented. The *Older Driver Highway Design Handbook* recommends the consistent use of a backplate with traffic signals wherever practical. Given that these roadways are major roadways with relatively high speeds, no right turn on red is a strategy which could better accommodate older drivers. Prohibited RTOR movements at skewed intersections such as this intersection are recommended in the

Older Driver Highway Design Handbook to better accommodate older drivers. This will slow motorists down who are staying on Route 129 turning right from Washington Street to Boston Street. The *Older Driver Highway Design Handbook* also recommends a minimum receiving lane width of 12 feet be accompanied by a 4 foot shoulder as shown in the figure below. It seems that this location may better accommodate older drivers if this recommendation was implemented as the lanes seem to be too narrow and there is a very small shoulder on Washington Street and no shoulder on Boston Street.

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.

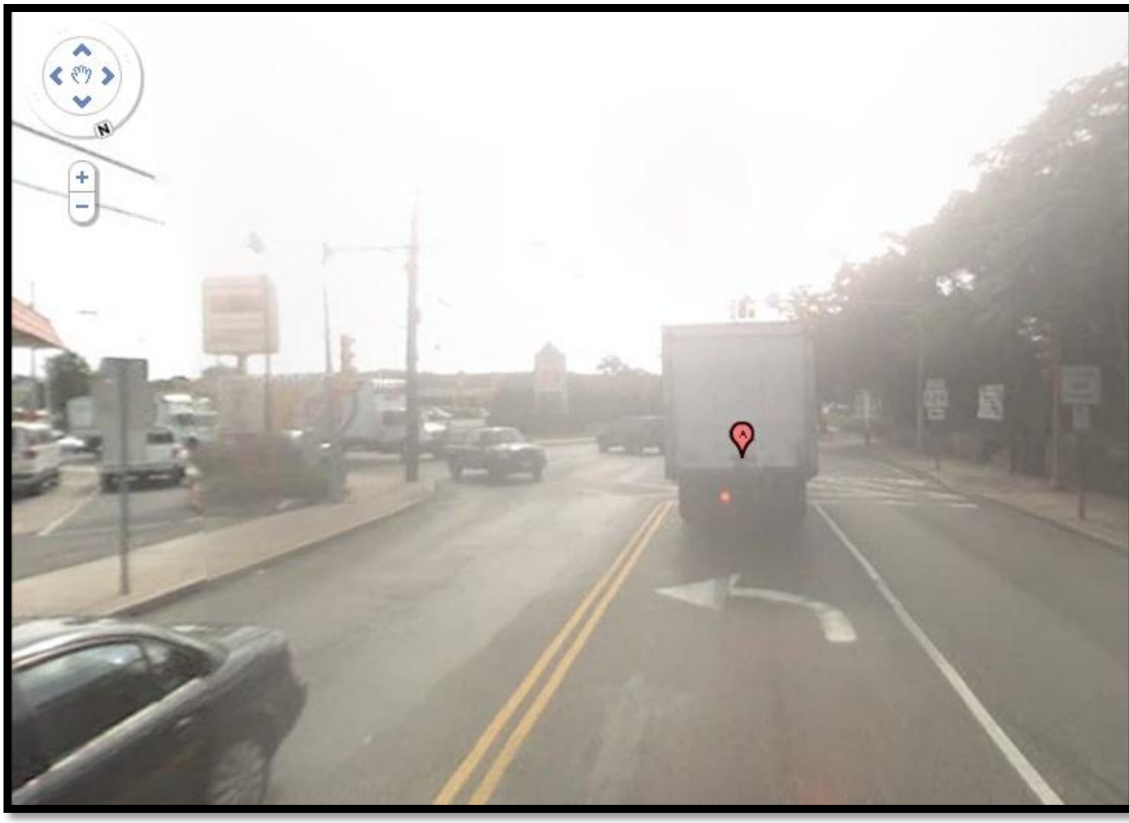


Figure 36. Intersection 217386 Street View

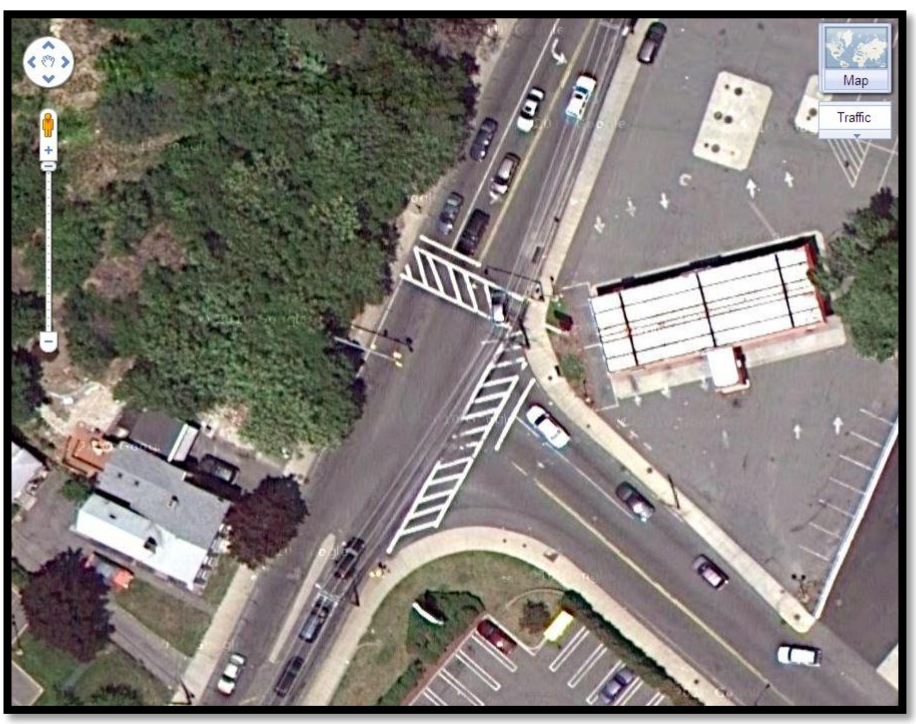


Figure 37. Intersection 217386 Satellite View

Intersection 201818 is the intersection of Main Street (Route 13) & Hamilton Street in Leominster, Massachusetts. It has an estimated total ADT of 29,145 vehicles per day. In 2007 and 2008, there were a total of **6 drivers age 65+ and 38 drivers between the ages of 35-55** involved in crashes at this intersection. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes at this intersection is greater than the statewide ratio of 1:3.87, this location has been identified as a high crash location for all age groups. All 6 older drivers involved in crashes at this four-way signalized intersection were involved in 2 vehicle crashes. Of the 6 older drivers involved in crashes at this intersection, 4 older drivers were involved in angle crashes and 1 driver was involved in a rear-end crash (the 6th driver manner of collision is unknown). The driver contributing code on the crash report form indicates that 1 driver failed to yield right of way and 1 driver was not paying attention. It should also be noted that all 6 older drivers were involved in property damage only crashes. This intersection was chosen as a location in which a road safety investigation be conducted as it ranked **2nd out of 36 for the age 35-55 frequency method**.

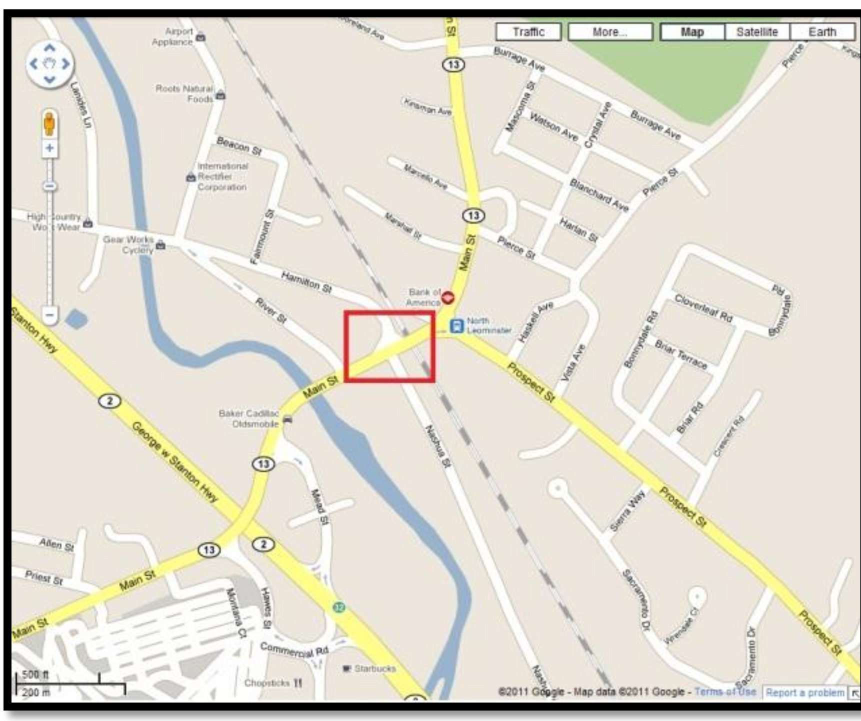


Figure 38. Intersection 201818 Google Map

The intersection of Main Street (Route 13) & Hamilton Street in Leominster, Massachusetts is a small and narrow intersection with very high volume. It is confusing to navigate through as the minor roadways (Hamilton Street & Nashua Street) have an offset, i.e. they are not directly across from one another (more specifically, Nashua Street is directly across from only the opposite travel lanes of Hamilton Street, making for a confusing setup). It is hard to tell where you are supposed to enter when maneuvering onto Hamilton Street. Furthermore, there is a sharp curve directly before the intersection when approaching from the north on Hamilton Street. While navigating through the intersection to head North onto Hamilton Street there are flashing yellow lights immediately following the intersection with signs saying "RED FLASHING FIRE APPARATUS ENTERING". This adds confusion to this intersection as well.There are significant queues at this intersection and many motorists taking right turns attempting to merge. There is only one overhead signal bar. The rest are located on the roadside or on islands. The installation of an overhead signal bar for motorists traveling east would be beneficial as the location of these signals are far away from the stop bar and hard to see. The use of raised channelization (sloping curbed medians) is recommended over painted channelization for left and right turn lane treatments at intersections. However, the island curb sides and surfaces should be treated with reflectorized paint and maintained at a minimum luminance contrast level of 3.0 or higher under low beam headlight illumination. These islands did not seem to be reflectorized. The *Older Driver Highway Design Handbook* also recommends that if right-turn channelization is present at an intersection, an acceleration lane providing for the acceleration characteristics of passenger cars as delineated in AASHTO specifications is recommended. This location has no acceleration lane. Although the street signs were in clear viewing position, there was minimal signage at this location. There also may be some sightline restrictions due to buildings at the intersection corners. Adding to the confusion are driveways in close proximity to the intersection.

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 39. Intersection 201818 Satellite View Showing Unique Geometry

Figure 40. Intersection 201818 - RED FLASHING FIRE APPARATUS ENTERING Signals and Signs

Figure 41. Intersection 201818 – Intersection Queues

Figure 42. Intersection 201818 – Raised Channelization

Intersection 307749 is the intersection of Washington Street (Route 1) & Everett Skinner Road in Plainville, Massachusetts. It has an estimated total ADT of 25,635 vehicles per day. In 2007 and 2008, there were a total of **5 drivers age 65+ and 9 drivers between the ages of 35-55** involved in crashes at this intersection. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes at this intersection is less than the statewide ratio of 1:3.87, this location has been identified as a location in which older drivers are overrepresented in crashes. All 5 older drivers were involved in two vehicle angle crashes. The driver contributing code on the crash report form indicates that 1 driver failed to yield right of way and 1 driver was distracted. It should also be noted that 3 drivers were involved in property damage only crashes while 1 driver was involved in non-fatal injury crashes, and **1 driver was involved in a fatal crash**. This intersection was chosen as a location in which a road safety investigation be conducted as it ranked **3rd out of 33 for the age 65+ severity index method.**

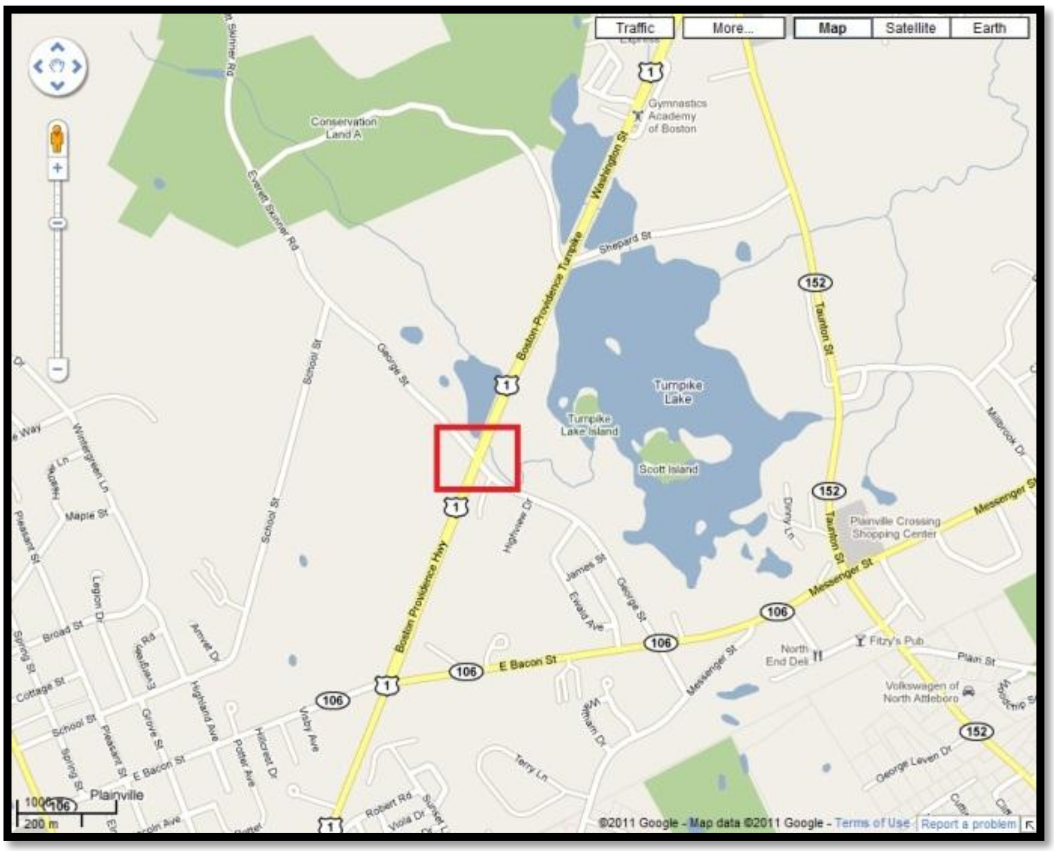


Figure 43. Intersection 307749 Google Map

The intersection of Washington Street (Route 1) & Everett Skinner Road in Plainville, Massachusetts is the intersection of a major four lane roadway and a small residential roadway, with stop signs on the minor roadway. When traveling on Route 1, this small roadway is hardly noticeable as it is very low volume. Furthermore, this intersection is currently skewed. Ideally, the intersecting roadways should meet at a 90-degree angle to better accommodate older drivers. At this location, it seems as though there is enough room for this change. The skewed geometry of this intersection in conjunction with the trees makes for limited sight distance, especially for older drivers who often have limited mobility in turning to appropriately scan the intersection. Furthermore, this location calls for a large gap and/or a fast reaction time as you are pulling out across multiple lanes of traffic onto a high speed roadway. Much of this roadway in other locations has a median with prevents motorists from taking left turns; however at this location left turns are allowed. Furthermore, one side of Everett Skinner Road approaches the intersection at an uphill grade, making for an even more difficult maneuver. Further investigation would be required to determine whether the vertical curve meets the recommendations presented in the *Older Driver Highway Design Handbook*.

Figure 44. Intersection 307749 Satellite View

Intersection 97032 is the intersection of Arcade Street & Mckinstry Avenue in Chicopee, Massachusetts. It has an estimated total ADT of 6,600 vehicles per day. In 2007 and 2008, there were a total of **8 drivers age 65+ and 6 drivers between the ages of 35-55** involved in crashes at this intersection. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes at this intersection is less than the statewide ratio of 1:3.87, this location has been identified as a location in which older drivers are overrepresented in crashes. All 8 older drivers involved in crashes at this intersection were involved in 2 vehicle angle crashes. The driver contributing code on the crash report form indicates that 1 driver exceeded the authorized speed limit, 1 driver failed to yield right of way, and 1 driver disregarded traffic signs, signals, or markings. It should also be noted that 2 drivers were involved in property damage only crashes while 6 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 257 for the age 65+ 'average of methods' method.**

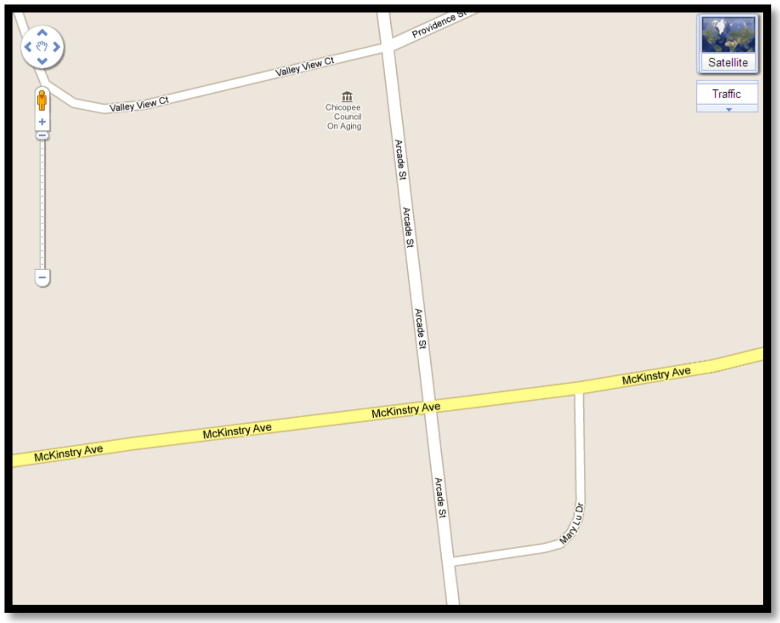


Figure 45. Intersection 97032 Google Map

The intersection of Mckinstry Avenue and Arcade Street is a four way intersection; stop controlled on the minor roadway (Arcade Street). Mckinstry Avenue is the major roadway, a relatively high speed roadway (35-40 mph). This intersection is small in nature. There is flashing red indication on the minor street (Arcade Street) and a flashing yellow on the major street (Mckinstry Avenue). There are also 'DANGEROUS INTERSECTION" signs on both approaches of Arcade Street. There may be some sightline restrictions because there are house on the corners which potentially obscure motorists views. It should be noted that the Chicopee Council on Aging is in very close proximity to this intersection and there are signs for it at the intersection. This means that a lot of older drivers use this intersection. The road is in poor condition and the pavement markings are faded. The *Older Driver Highway Design Handbook* recommends a minimum receiving lane width of 12 feet be accompanied by a 4 foot shoulder as shown in the figure below. It seems that this location may better accommodate older drivers if this recommendation was implemented. Additionally, 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. Motorists are required to go way over stop bar in order to see and make a turn. However, the stop bars are already close to the intersecting roadway.

Figure 46. Intersection 97032 Satellite View

Figure 47. Intersection 97032 Street View

Next, relationships between the method(s) used to identify the high crash location and the recommended countermeasures proposed for the specified location were identified. This can provide transportation professionals with a list of countermeasures to consider depending upon which method was utilized in identifying the specified location.

Relationships between the Method(s) Used and the Proposed Countermeasures - Intersections

Age 65+ Frequency Method and Age 65+ EPDO Index Method

Observed correlations between locations

- Four-way signalized intersections
- Skewed intersections
- Large intersection (4 lane roadway & 2 lane roadway)
- High volume (ADT = 13,309 & 16,400)
- High speed (35-40 mph)
- Long left turn maneuvers
- Lack of protected left turn indications or dedicated left turn lanes
- Lack of “LEFT TURN YEILD ON GREEN” indication signs overhead
- No signal backplates
- Driveways and/or intersections in close proximity
- Possible sightline restrictions
- Possible glare issues

Possible Countermeasures to consider when using the age 65+ frequency method or age 65+ EPDO index method to identify high crash locations for older drivers

- Dedicated left turn lanes
- Protected left turn indications
- "LEFT TURN YIELD ON GREEN" signs on overhead signal bars
- Pavement markings which scribe a path through the intersection for left turn maneuvers
- Fix geometry to that roadways meet at 90 degrees
- Repave roadways/fill pot holes
- Repaint pavement markings
- Prohibited RTOR movements w/ appropriate signage
- Signal backplates
- Fixed lighting installations
- All-red clearance interval per the ITE expressions
- Check standards for the vertical intensity distribution

Many of the same findings were observed for the locations which ranked high in the **age 35-55 frequency method**, when considering older drivers in particular (as previously discussed these locations were still considered high crash locations for older drivers as they had a minimum of 5 older drivers involved in crashes in 2007 and 2008). These locations were also signalized and high volume (ADT = 20,300 & 29,145) and high speed (35-40mph). Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes at these intersections is greater than the statewide ratio of 1:3.87, these locations are considered high crash locations for all age groups. There are important differences to note, however. These intersections are unique and irregular as compared to those which were selected based solely upon the frequency of older drivers involved in crashes in which the intersection seemed for the most part 'normal' and intersections we see every day. For example, one of these intersections was a four way intersection in which the minor roadways were offset from one another creating a confusing geometry in conjunction with confusing signage and flashing lights for fire apparatus and a sharp curve while the other was a t-intersection in which the major roadway required a left turn maneuver. These locations did have left turn lanes unlike the 65+ frequency locations. However, they also had possible sightline and glare issues.

Age 65+ Spot Rate Method and EPDO Rate Method

Observed correlations between locations

- Low volume (ADT = 1200 & 900) – basis for ranking high in this method
- Stop sign controlled on minor roadway
- Narrow roads
- Faded pavement markings

- Sightline restrictions
- Buildings close to intersection
- High speed on major (35-40 mph)

Possible Countermeasures to consider when using the age 65+ spot rate method and the EPDO rate method to identify high crash locations for older drivers

- Widen roadways and shoulders (12 foot lanes with 4 foot shoulders are recommended)
- "CROSS TRAFFIC DOES NOT STOP" sign in conjunction with stop signs
- "STOP AHEAD" warning signs
- Movement of stop bars or stop signs
- Fixed lighting installations
- Flashing yellow beacon on major roadway and/or flashing red beacon on minor roadway
- Removal of bushes and/or other objects which may be obstructing motorists' view

The age **35-55 spot rate method** yielded the same results as the average daily traffic at this high crash locations was very low.

The **age 65+ severity index method** brings those high crash locations with a fatal crashes or a significant number of injury crashes to attention. As a result the locations are a mixture of the results above, i.e. one four-way signalized intersection, a stop controlled intersection, and an intersection which a confusing one-way scheme in which vehicles are not actually required to stop.

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.

Roadway Segment Road Safety Investigations

Roadway Segment 18353 is located on Washington Street (U.S. Highway - Route 1) in Attleboro, Massachusetts. It extends from Como Drive to approximately 74 feet south of Cumberland Avenue. This segment is 0.3406 miles long and has an average daily traffic (ADT) of 11600 vehicles. In 2007 and 2008, there were a total of **10 drivers age 65+ and 31 drivers between the ages of 35-55** involved in crashes on this segment. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes on this segment is less than the statewide ratio of 1:4.76, this location has been identified as a location in which older drivers are overrepresented in crashes. Of the 10 older drivers involved in crashes on this roadway segment, 7 drivers were involved in 2 vehicle crashes while 3 drivers were involved in 3 vehicle crashes. Furthermore, 3 drivers were involved in angle crashes while 5 drivers were involved in rear-end crashes and 1 driver was involved in a head-on collision (the 10^{th} driver manner of collision is unknown).

The driver contributing code on the crash report form indicates that 2 drivers were faulted for following too closely, 1 driver had glare, 2 drivers failed to yield right of way, and 1 driver was not paying attention. It should also be noted that 7 drivers were involved in property damage only crashes while 3 drivers were involved in non-fatal injury crashes. This roadway segment was chosen as a location in which a road safety investigation be conducted as it ranked **2 out of 8 for the age 65+ crash frequency method, 3 out of 28 for the age 35-55 crash frequency method, and 4 out of 23 for the age 65+ EPDO index method.**

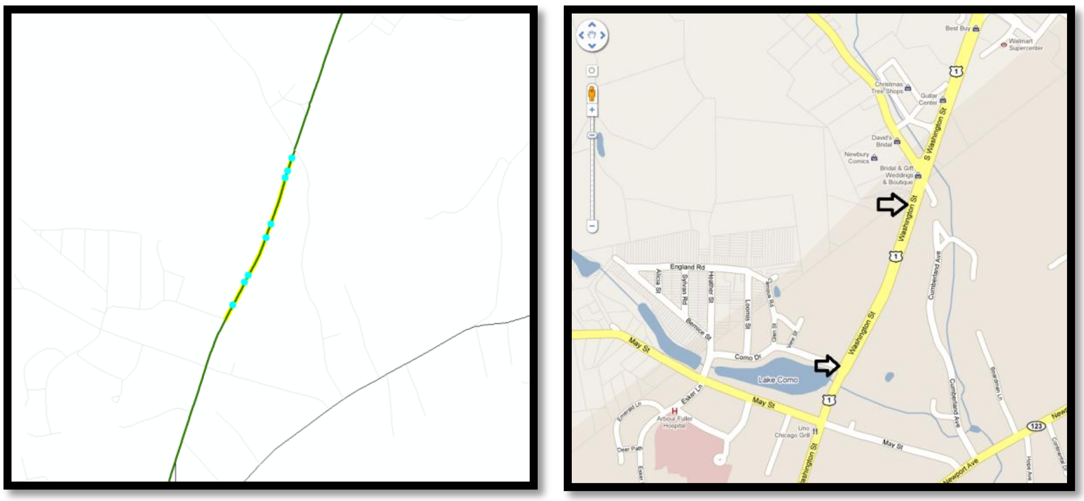


Figure 48. Roadway Segment 18353 ArcGIS and Google Maps

Roadway Segment 18353, located on Washington Street (U.S. Highway - Route 1) in Attleboro, Massachusetts, is a four lane roadway that is relatively high volume. The speed limit it 40 mph. There are a lot of businesses and motorists entering in and out of the many driveways. There are left turn lanes for some driveways which change often. The lane configurations change multiple times throughout this segment creating a confusing scenario. There is no barrier between the north and south directions of travel and only a painted median on the pavement in some locations. Furthermore, there is only a very small shoulder present. A raised median treated with reflectorized paint would be ideal for this location. This would prevent drivers from making left turns out of businesses.Alternatively, right turn only signs could be placed at the exits to these businesses. Furthermore, a shoulder of greater width would be beneficial for drivers taking right turns into driveways as this would reduce rear-end crashes. It may be that some of the driveways could be merged. If enough could be merged then the a signalized intersection may be possible.

Figure 49. Intersection 18353 Street View Left Turn Configuration

Roadway Segment 102658 is located on Ripley Road in Cohasset, Massachusetts. It extends from Smith Place to 0.0347 miles east of Smith Place. This segment is 0.0347 miles long and has an average daily traffic (ADT) of 3000 vehicles. In 2007 and 2008, there were a total of **5 drivers age 65+ and 5 drivers between the ages of 35-55** involved in crashes on this segment. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes on this segment is less than the statewide ratio of 1:4.76, this location has been identified as a location in which older drivers are overrepresented in crashes. All 5 older drivers who were involved on crashes on this segment were involved in 2 vehicle crashes. Furthermore, 1 driver was involved in an angle crash while 3 drivers were involved in sideswipe same direction crashes (the 5th driver manner of collision is unknown). The driver contributing code on the crash report form indicates that 1 driver was not paying attention. It should also be noted that all 5 drivers were involved in property damage only crashes. This roadway segment was chosen as a location in which a road safety investigation be conducted as it ranked **5 out of 175 for the age 65+ crash density method, 5 out of 137 for the age 65+ crash rate method, 3 out of 179 for the age 65+ section rate method, 4 out of 174 for the age 35-55 section rate method, and 2 out of 149 for the age 65+ 'average of methods' method**.

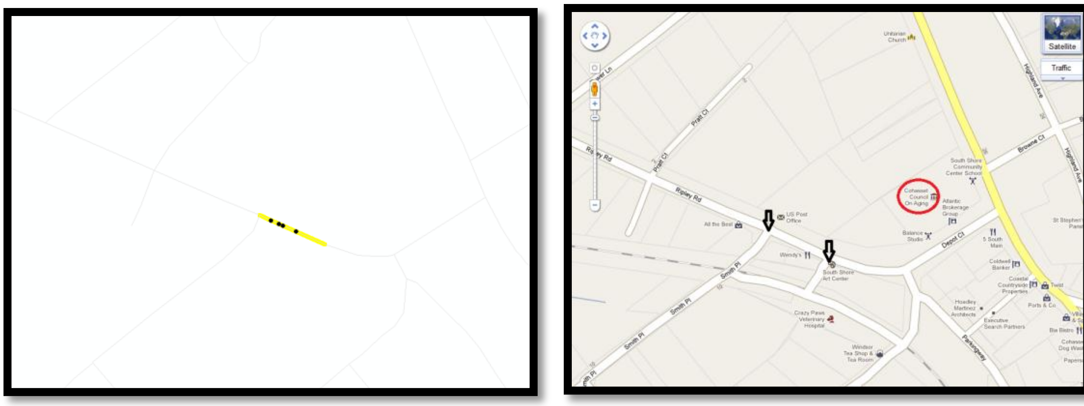


Figure 50. Roadway Segment 102658 ArcGIS and Google Maps

This roadway segment (102658) is located in the downtown area of Cohasset, Massachusetts. As such, the speed limit is very slow at 20 mph. The roadway appears narrow and the roadway markings are barely visible. It appears that the post office within the boundaries of this segment has a constant flow of in and out traffic. Furthermore, drivers parallel park in close proximity to the post office on both sides of the roadway, which may be causing sightline restrictions for drivers exiting the post office. Additionally, drivers park around the curve, just east of this roadway segment which may also be an issue. There are no signals and minimal signage in this area. Drivers exiting Smith Place may also be causing conflicts with those exiting the post office. It seemed to be well enforced as an officer was parked and walking around at the time of the site visit. It is interesting to note that the Cohasset Council on Aging is in very close proximity to this older driver high crash location site and it is fair to say that there is a high population of seniors in this area. To reduce crashes in this area, a parking ban may be efficient during peak hours or at times when the crashes seem to be taking place. Additionally, parking should be banned within a certain distance of the post office and around the curve. A flashing yellow beacon may be beneficial so that drivers use caution when passing through this area, in particular the post office.

Figure 51. Intersection 102658 Bird's Eye View

Roadway Segment 123201 is located on Bedford Street (State Route 18) in East Bridgewater, Massachusetts. It extends from Abbey Lane to Whitman Street. This segment is 0.7 miles long and has an average daily traffic (ADT) of 19,600 vehicles. In 2007 and 2008, there were a total of **10 drivers age 65+ and 7 drivers between the ages of 35-55** involved in crashes on this segment. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes on this segment is less than the statewide ratio of 1:4.76, this location has been identified as a location in which older drivers are overrepresented in crashes. The figure below depicts an ArcGIS snapshot view of the roadway segment which is highlighted in yellow with the locations along the segment in which older drivers were involved in crashes highlighted in light blue. [It should be noted that roadway segment 123203, which extends 0.3279 miles north of roadway segment 123201 had an additional 4 older drivers involved in crashes in the same timeframe and therefore was also deemed a roadway segment with a high number of older drivers involved in crashes. As such, this segment will be examined in the field. In the figure below, this segment is also highlighted in yellow; however, the locations along the segment in which older drivers were involved in crashes are shown in black.] Of the 10 older drivers involved in crashes on this roadway segment of particular interest (123201), 8 drivers were involved in 2 vehicle crashes while 2 drivers were involved in 3 vehicle crashes. Furthermore, 1 driver was involved in an angle crash while 7 drivers were involved in rear-end crashes and 2 drivers were involved in sideswipe same direction crashes. The driver contributing code on the crash report form indicates that 3 drivers were faulted for following too closely and 3 drivers were not paying attention. It should also be noted that 7 drivers were involved in property damage only crashes while 3 drivers were involved in non-fatal injury crashes. This roadway segment was chosen as a location in which a road safety investigation be conducted as it ranked **2 out of 8 for the age 65+ crash frequency method and 4 out of 23 for the age 65+ EPDO index method**.

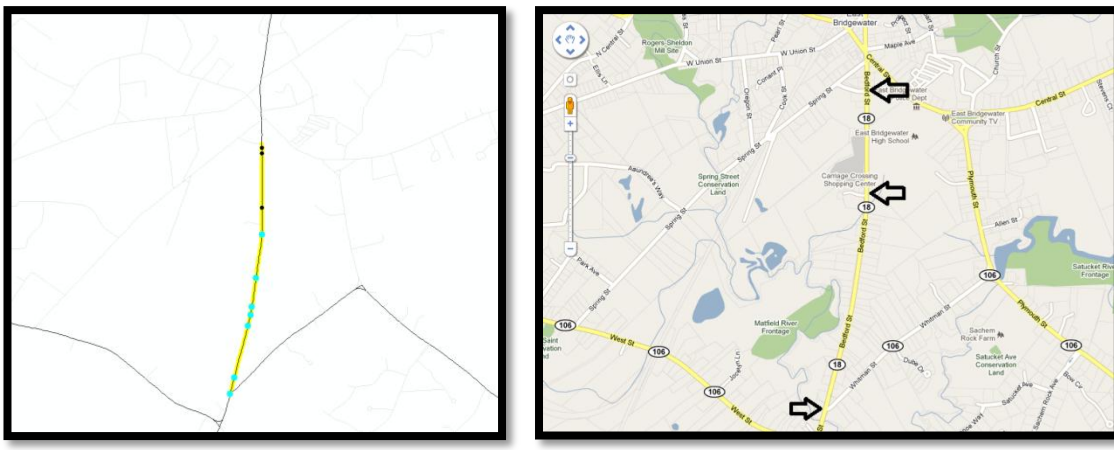


Figure 52. Roadway Segment 123201 ArcGIS and GIS Maps

Roadway Segment 123201, located on Bedford Street (State Route 18) in East Bridgewater, Massachusetts, is a high volume roadway. This segment is a 4 lane roadway on the south end at the intersection of Route 18 and Whitman Street but the majority of the segment is a 2 lane roadway. The speed limit it 40 mph. There are motorists entering in and out of the many driveways on this segment, however this segment is mostly residential. There is no left turn or right turn only lanes on this segment and the segment has a very small shoulder. The centerline switches from a double yellow line to areas with permitted passing zones for one direction and areas with permitted passing zones for both directions of travel. There is no barrier between the north and south directions of travel and no medians, except for a painted median on the very north end of the segment near Abbey Lane. The lines are faded and need to be repainted and there are no edgelines or curbs in some spots. There is also minimum signage in this area. There are some minor horizontal and vertical curves on this roadway segment but a further investigation would have to be conducted to determine the radii and whether or not the recommendations in the *Older*

Driver Highway Design Handbook are met. A reflectorized median or barrier would prevent drivers from making left turns out of driveways. Alternatively, “RIGHT TURN ONLY” signs could be utilized. Given that rear-end crashes seem to be the main problem for older drivers at this intersection; a larger shoulder would be a way to reduce this issue. The following are recommendations provided by the *Older Driver Highway Design Handbook* for passing zone length, passing sight distance, and passing/overtaking lanes on two-lane highways. The following should be checked in more detail to see if these recommendations are met on this roadway segment:

1. A minimum passing zone length of 350 m (1,150 ft) is recommended for any facility with an operating speed of 64 km/h (40 mi/h) or greater.
2. A minimum passing sight distance (MUTCD definition [Federal Highway Administration, 1988]) of 215 m (705 ft) is recommended for any facility with an operating speed of 64 km/h (40 mi/h) or greater.
3. Use of special size (1,200 mm x 1,600 mm x 1,600 mm [48 in x 64 in x 64 in]) NO PASSING ZONE pennant (W14-3) as a high-conspicuity supplement to conventional centerline pavement markings at the beginning of no passing zones is recommended.
4. To the extent feasible for new or reconstructed facilities, excepting those with low traffic volume, the implementation of passing/overtaking lanes (each direction) at intervals of no more than 5 km (3.1 mi) is recommended.

Roadway Segment 137755 is located on Brightman Street in Fall River, Massachusetts. It extends from N. Davol Street to Lindsey Street. This segment is only 0.011 miles long and has an average daily traffic (ADT) of 9100 vehicles. In 2007 and 2008, there were a total of **4 drivers age 65+ and 11 drivers between the ages of 35-55** involved in crashes on this segment. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes on this segment is less than the statewide ratio of 1:4.76, this location has been identified as a location in which older drivers are overrepresented in crashes. Of the 4 older drivers involved in crashes on this roadway segment, 2 drivers were involved in 1 vehicle crashes and 2 drivers were involved in 2 vehicle crashes. Furthermore, 1 driver was involved in an angle crash, 1 driver was involved in a rear-end crash, and 2 drivers were involved in single vehicle crashes. The driver contributing code on the crash report form indicates that 1 driver was faulted for not paying attention and 1 driver had glare. It should also be noted that all 4 drivers were involved in property damage only crashes. This roadway segment was chosen as a location in which a road safety investigation be conducted as it ranked **1 out of 175 for the age 65+ crash density method, 1 out of 174 for the age 35-55 crash density method, 4 out of 179 for the age 65+ section rate method, and 3 out of 174 for the age 35-55 section**

rate method. Its high ranking using these methods is due to the extremely small size of this roadway segment.

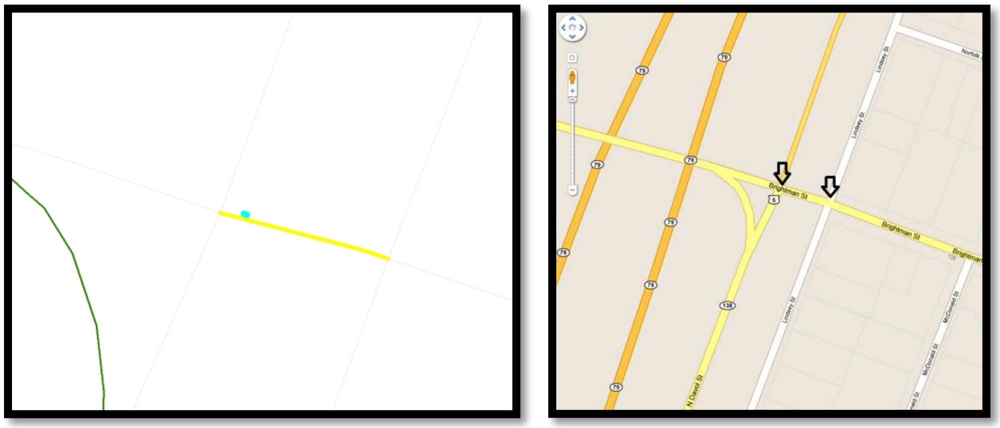


Figure 53. Roadway Segment 137755 ArcGIS & Google Maps

Roadway Segment 137755, located on Brightman Street in Fall River, Massachusetts, is a very small roadway segment, encompassing only one very unique intersection. This area is now under construction adding to the complexity of this segment at the time of the site visit. The construction prohibits vehicles from making a right turn onto the segment from N. Davol Street. An off ramp with motorists traveling at high speeds enters onto this roadway segment which leads into a very residential area. When traveling in the opposite direction there is a light which is not functioning. Additionally, there is no clear signage at this location. Solar glare also seems to be an issue at this location. This roadway segment needs better signage. Possibly the addition on “ONE WAY” signs, “WARNING SIGNS”, and “DO NOT ENTER” signs. Pavement markings would also be useful.

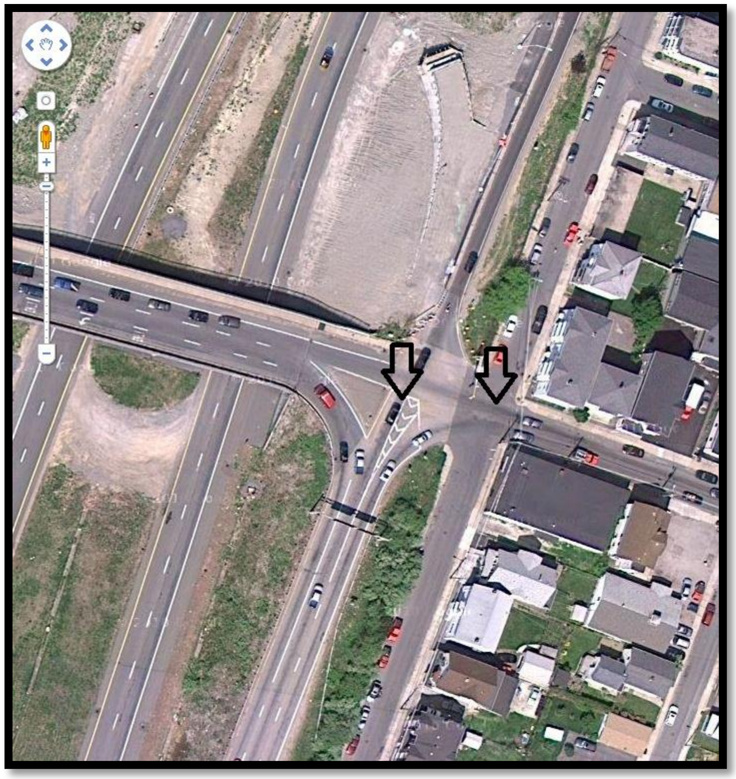


Figure 54. Roadway Segment 137755 Satellite View

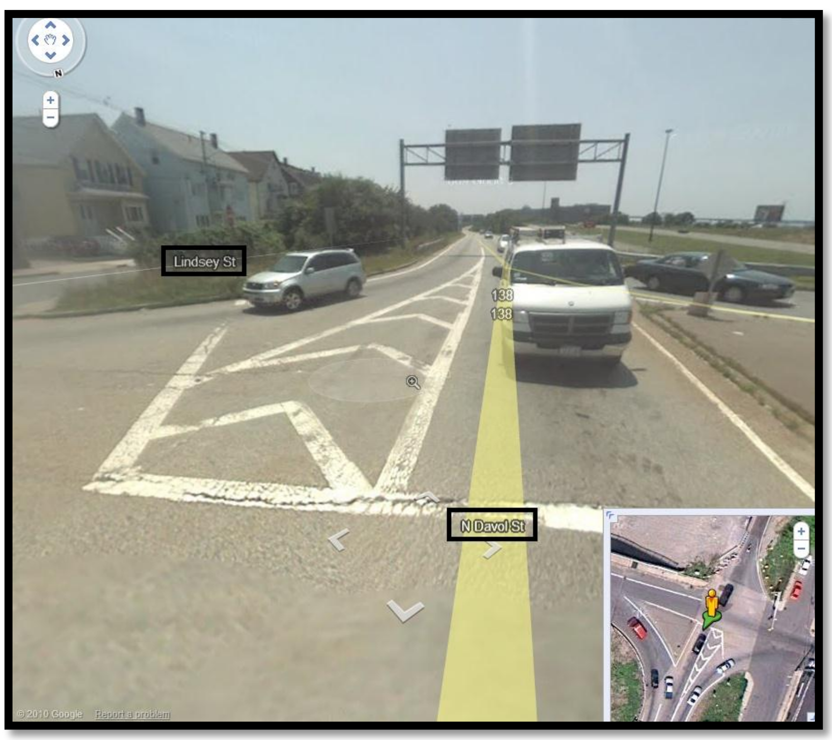


Figure 55. Roadway Segment 137755 Off-Ramp to Segment

Figure 56. Roadway Segment 137755 – Road Closure and Solar Glare

<u>Roadway Segment 155628</u> is located on Pearson Boulevard in Gardner, Massachusetts. It extends from Elm Street east to about the Subway entrance. This segment is 0.1452 miles long and has an average daily traffic (ADT) of 4000 vehicles. In 2007 and 2008, there were a total of **4 drivers age 65+ and 12 drivers between the ages of 35-55** involved in crashes on this segment. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes on this segment is less than the statewide ratio of 1:4.76, this location has been identified as a location in which older drivers are overrepresented in crashes. All 4 older drivers involved in crashes on this roadway segment were involved in 2 vehicle crashes. Furthermore, 3 drivers were involved in angle crashes (the 4^{th} driver manner of collision is unknown). The driver contributing code on the crash report form indicates that 1 driver was faulted for not paying attention and 1 driver failed to yield right of way. It should also be noted that 3 drivers were involved in property damage only crashes while 1 driver was involved in a non-fatal injury crash. This roadway segment was chosen as a location in which a road safety investigation be conducted as it ranked **4 out of 159 for the age 35-55 crash rate method.**

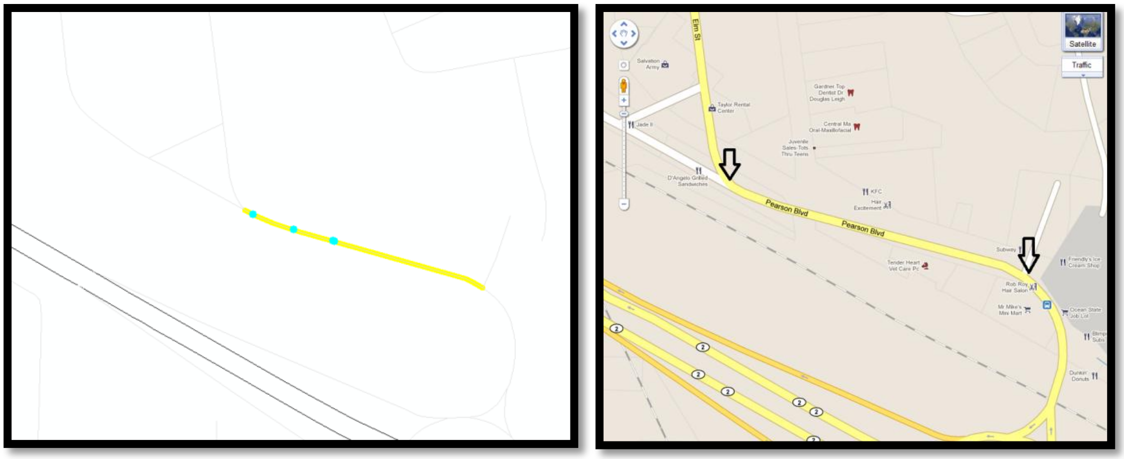


Figure 57. Roadway Segment 155628 ArcGIS and Google Maps

Roadway Segment 155628, located on Pearson Boulevard in Gardner, Massachusetts, is a busy area with a lot of businesses and driveways with motorists pulling in and out to make right and left hand turns. The pavement markings which do exist are very faded and incorrect. In one instance, a left turn arrow exists for the shell station which is to the left of the double yellow centerline, with oncoming traffic in the opposite direction. This is very confusing and a big problem. Similarly there are some instances in which there are no centerlines or line delineation but still left turn arrows on the pavement. Furthermore, the number of lanes which exist is unclear and the shoulder is very small. Additionally, the signalized intersection at Elm Street looks confusing and could be improved. First and foremost, the pavement markings need to be re-painted correctly. Ideally, a larger shoulder would be included to help reduce the chance of rear-end crashes. Ideally, the left turn lanes would be offset from one another as shown in the figure below and as recommended in the *Older Driver Highway Design Handbook* for optimal sight distance. However, if they were configured correctly, the left turn lanes would be more efficient. “RIGHT TURN ONLY” signs could be installed at business exits to reduce angle crashes by eliminating left turns. If space was available, a median would help to separate traffic. This would reduce the number of locations motorists are turning. Driveways could most likely be combined as well.

Figure 58. Roadway Segment 155628 Satellite View

Figure 59. Roadway Segment 155628 Street View – Poor Pavement Markings

Roadway Segment 242382 is located on Pelham Street in Methuen, Massachusetts. It extends from Aegean Drive to the ramp from Pelham Street to Route 93 Southbound. This segment is 0.218 miles long and has an average daily traffic (ADT) of 2900 vehicles. In 2007 and 2008, there were a total of **4 drivers age 65+ and 5 drivers between the ages of 35-55** involved in crashes on this segment. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes on this segment is less than the statewide ratio of 1:4.76, this location has been identified as a location in which older drivers are overrepresented in crashes. Of the 4 older drivers involved in crashes on this roadway segment, 2 drivers were involved in 2 vehicle crashes and 2 drivers were involved in 3 vehicle crashes. All 4 older drivers were involved in rear-end crashes. The driver contributing code on the crash report form indicates that 1 driver was faulted for not paying attention. It should also be noted that 1 driver was involved in a property damage only crash while 3 drivers were involved in non-fatal injury crashes. This roadway segment was chosen as a location in which a road safety investigation be conducted as it **ranked 4 out of 19 for the age 65+ severity index method and 4 out of 159 for the age 65+ EPDO rate method**.

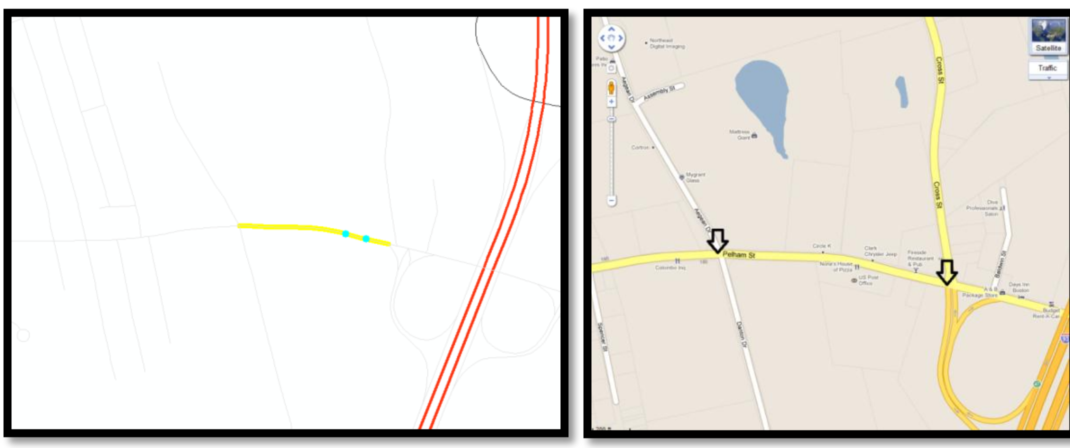


Figure 60. Roadway Segment 242382 ArcGIS and Google Maps

Roadway Segment 242382, located on Pelham Street in Methuen, Massachusetts is a 2 lane roadway in a busy area with a lot of driveways as you approach the on ramp to I-93. There are two locations with dedicated left turn lanes (one for the Irving gas station &one for the convenient store). Otherwise it is hard to make left turns. It would be ideal to eliminate left turns at other spots by using "RIGHT TURN ONLY" signage or to install a median. There is currently painted channelization/medians in a couple locations on this segment. The shoulder is very small and could be widening to reduce rear end crashes. Similarly, the traffic backs up as you approach the on-ramp which could be a factor in why there are a high number of rear-end crashes at this location. This intersection at the on-ramp to I-93 has three lanes (a left turn lane, a through lane, and a right turn lane). There is no passing on this segment. The pavement markings are faded in some areas on the segment.

Figure 61. Roadway Segment 242382 Satellite View

Figure 62. Roadway Segment 242382 – Entrance to I-93 Southbound

Figure 63. Roadway Segment 242382 – Several Driveways on Segment

Roadway Segment 259307 is located on West Central Street (State Route 135) in Natick, Massachusetts. It extends from Speen Street Cemetery Street. This segment is 0.85 miles long and has an average daily traffic (ADT) of 15300 vehicles. In 2007 and 2008, there were a total of **10 drivers age 65+ and 21 drivers between the ages of 35-55** involved in crashes on this segment. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes on this segment is less than the statewide ratio of 1:4.76, this location has been identified as a location in which older drivers are overrepresented in crashes. Figure 64below depicts an ArcGIS snapshot view of the roadway segment which is highlighted in yellow with the locations along the segment in which older drivers were involved in crashes highlighted in light blue. [It should be noted that roadway segment 259660, also located on West Central Street (State Route 135) but west of roadway segment 259307, is in close proximity. This segment had an additional 4 older drivers involved in crashes in the same timeframe and therefore was also deemed a roadway segment with a high number of older drivers involved in crashes. As such, this segment will be examined in the field in conjunction with this road safety investigation. Figure 64 also depicts this segment is also highlighted in yellow; however, the locations along the segment in which older drivers were involved in crashes are shown in black.] Of the 10 older drivers involved in crashes on this roadway segment, 4 drivers were involved in 1 vehicle crashes, 4 drivers were involved in 3 vehicle crashes, 1 driver was involved in a 2 vehicle crash, and 1 driver was involved in a 4 vehicle crash. Furthermore, 4 drivers were involved in angle crashes, 4 drivers were involved in single vehicle crashes, and 2 drivers were involved in rear-end crashes. The driver contributing code on the crash report form indicates that 2 drivers were faulted for not paying attention, 1 driver failed to yield right of way, and 1 driver disregarded traffic signs, signals, or road markings. It should also be noted that 3 drivers were involved in property damage only crashes while 7 drivers were involved in non-fatal injury crashes. This roadway segment was chosen as a location in which a road safety investigation be conducted as it ranked **2 out of 8 for the age 65+ crash frequency method and 1 out of 23 for the age 65+ EPDO Index method**.

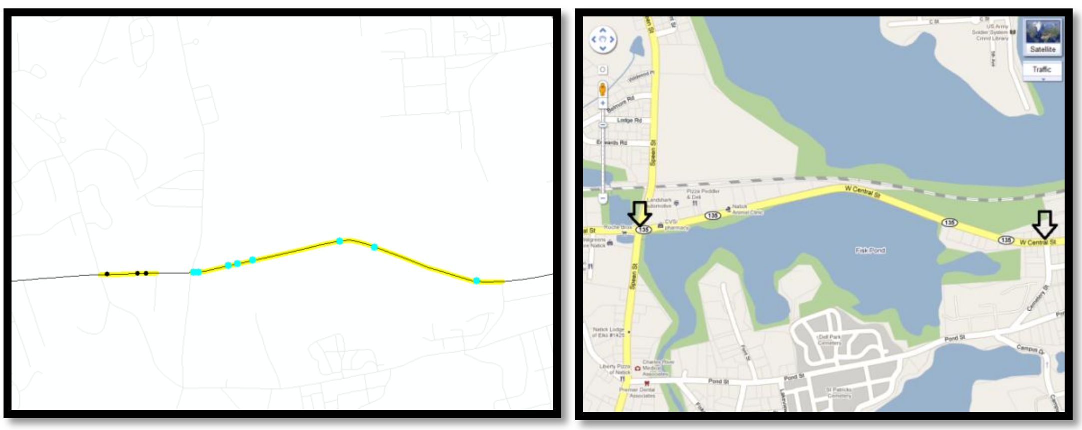


Figure 64. Roadway Segment 259307 ArcGIS and Google Maps

Roadway Segment 259307, located on West Central Street (State Route 135) in Natick, Massachusetts, is a 2 lane roadway with a double yellow centerline throughout. The majority of the crashes seem to occur on the west side of this roadway segment. At the signal for Speen Street you cannot take a left due to a road closure for construction, so the left turn only lane is not being utilized. This intersection is congested. The CVS driveway is in close proximity to the intersection and the queue is past the CVS driveway making it difficult to pull out of CVS, especially when taking a left turn. There is also a Mobil gas station and Dunkin Donuts in close proximity where the queue often goes past as well creating the same scenario. This roadway has somewhat high speeds and is relatively narrow. There is a curve within the roadway segment which also seems to be a spot prone to crashes. There is a road narrows sign at the intersection at Speen Street which may be a reason as to why the roadway segment following this one is also a high crash location. This area is also busy with a lot of driveways. In proximity to the intersection at Speen Street it would be beneficial to have a raised reflectorized median prohibiting left turn movements out of driveways. Alternatively, "RIGHT TURN ONLY SIGNS" could be utilized. It would be beneficial to make the driveways of CVS and Dunkin Donuts/Mobil into one driveway or to make these driveways right turn only. Alternatively, the entrance/exit of CVS on West Central Street could be and entrance only, while the entrance/exit on Speen Street could be an exit only. Perhaps the signal at Speen Street could be retimed to reduce queues on this segment as it seems as though this queue is a major problem. A larger paved shoulder could be provided around the horizontal curve on this segment.

The *Older Driver Highway Design Handbook* recommends a minimum lane-plus-paved-shoulder of 18 feet through the length of arterial horizontal curves greater than or equal to 3 degrees of curvature. Additionally, the installation of centerline raised-pavement markers throughout curves with radii less than 3,281 feet is recommended as well as the installation of roadside delineation devices on horizontal curves with radii less than 600 feet in the *Older Driver Highway Design Handbook*. Further investigation would have to be done to determine what the radii of this curve. Dangerous curve warning sings or signs warning of a curve could also be implemented.

Figure 65. Roadway Segment 259307 – Queue at Intersection of Speen Street

Figure 66. Roadway Segment 259307 – Curve

Roadway Segment 279865 is located on Turnpike Street (State Route 114) in North Andover, Massachusetts. It extends from Hillside Road to Mill Road. This segment is 0.6334 miles long and has an average daily traffic (ADT) of 25791 vehicles. In 2007 and 2008, there were a total of **5 drivers age 65+ and 33 drivers between the ages of 35-55** involved in crashes on this segment. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes on this segment is greater than the statewide ratio of 1:4.76, this location has been identified as a high crash location for all road users. Of the 5 older drivers involved in crashes on this roadway segment, 3 drivers were involved in 2 vehicle crashes and 2 drivers were involved in 3 vehicle crashes. All 5 drivers were involved in rear-end crashes. The driver contributing code on the crash report form indicates that 1 driver was faulted for following too closely. It should also be noted that 2 drivers were involved in property damage only crashes while 3 drivers were involved in non-fatal injury crashes. This roadway segment was chosen as a location in which a road safety investigation be conducted as it ranked **2 out of 28 for the age 35-55 crash frequency method**.

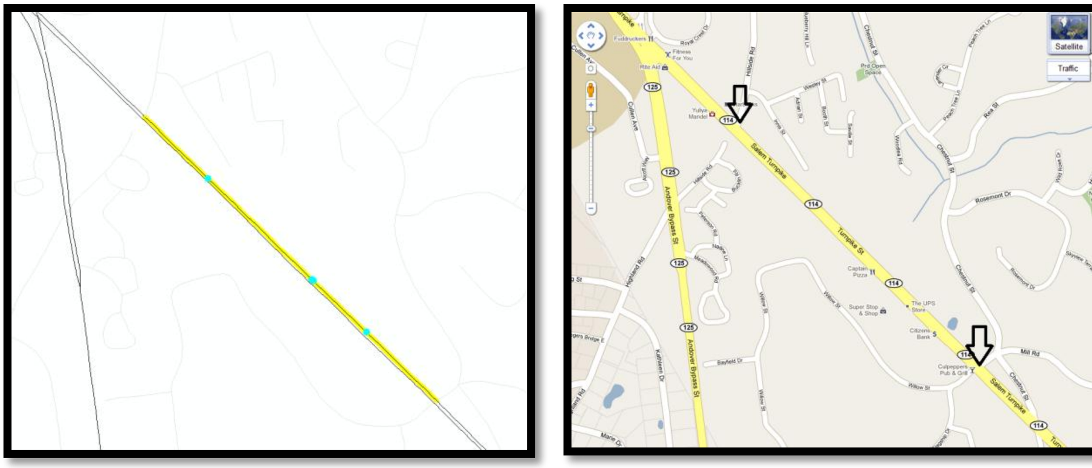


Figure 67. Roadway Segment 279865 ArcGIS and Google Maps

Roadway Segment 279865, located on Turnpike Street (State Route 114) in North Andover, Massachusetts, is a high volume roadway with relatively high speeds. The lane configuration changes multiple times throughout the segment. On the west end (beginning at Hillside Road), this roadway segment is a 3 lane roadway with 2 lanes heading east and 1 west separated by a double yellow line and is residential with some businesses. As you head east, this segment becomes a 3 lane roadway followed by a 5 lane roadway with one travel lane in each direction and a center lane for turning vehicles. Given that this turning lane has no arrows for specific movements (other than one left turn arrow in one spot) it seems confusing in nature. The segment then approaches 2 signalized intersections before ending. At the east part of the segment there are more businesses and more traffic. Throughout this segment the shoulder is very small and the lines are faded and are in need of being re-painted especially given the constant change in road configuration. Given that the five older drivers involved in crashes on this segment were involved in rear-end crashes, wider shoulders would be beneficial. The problem may also be that people are pulling out right in front of another motorist, causing a rear end crash. Wider shoulders would also relieve this situation. Perhaps there are driveways which could be condensed to limit the number of spots drivers are pulling into traffic. Perhaps eliminating the center lane turn lane for both directions would be helpful. This sign is not too common and may be confusing to older drivers. It may also be beneficial to move the location in which 2 lanes merge to 1 lane as this is right at a location in which many motorists are entering and exiting driveways.

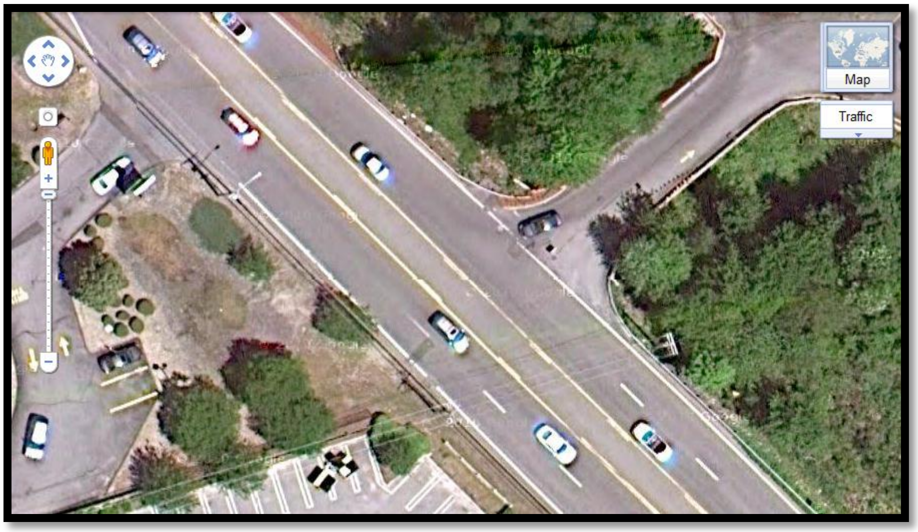


Figure 68. Roadway Segment 279865 – Centerlane Turn Lane

Roadway Segment 300255 is located on Summit Street in Peabody, Massachusetts. It extends from Christina Drive to Lynnfield Street. This segment is 0.1138 miles long and has an average daily traffic (ADT) of 2500 vehicles. In 2007 and 2008, there were a total **of 4 drivers age 65+ and 13 drivers between the ages of 35-55** involved in crashes on this segment. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes on this segment is less than the statewide ratio of 1:4.76, this location has been identified as a location in which older drivers are overrepresented in crashes. Of the 4 older drivers involved in crashes on this roadway segment, 3 drivers were involved in 2 vehicle crashes and 1 driver was involved in a 3 vehicle crash. Furthermore, 3 drivers were involved in rear-end crashes while 1 driver was involved in an angle crash. The driver contributing code on the crash report form indicates that 1 driver was faulted for failing to yield right of way, 1 driver was not paying attention, and 1 driver's visibility was obstructed. It should also be noted that 1 driver was involved in property damage only crashes while 3 drivers were involved in non-fatal injury crashes. This roadway segment was chosen as a location in which a road safety investigation be conducted as it **ranked 2 out of 159 for the age 35-55 crash rate method, 5 out of 174 for the age 35-55 section rate method, 4 out of 19 for the age 65+ severity index method, and 3 out of 159 for the age 65+ EPDO rate method.**

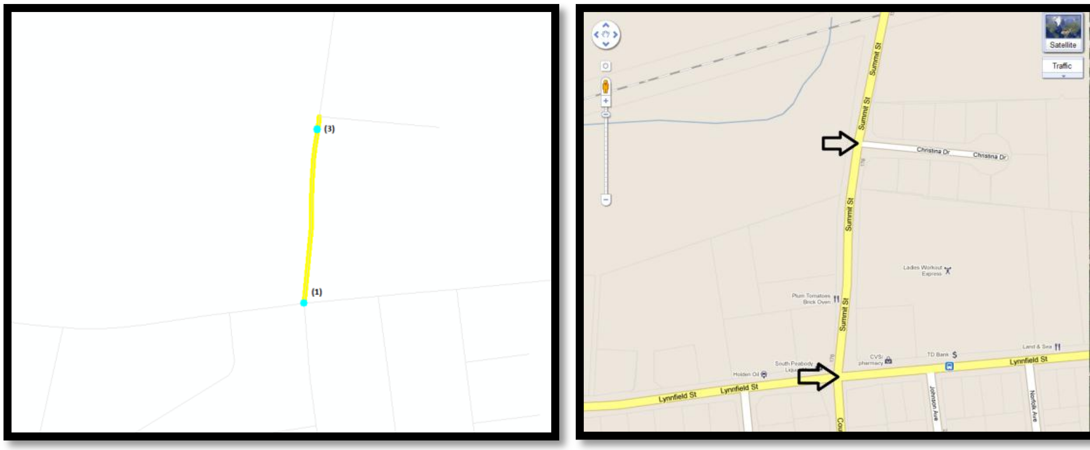


Figure 69. Roadway Segment 300255 ArcGIS and Google Maps

This roadway segment (300255) seemed relatively high volume (the ADT seems to be an underestimate). 3 of the 4 older driver crashes appear (according to ArcGIS) to have occurred around the entrance to the plaza. The plaza currently has 3 entrances and 3 exits for a small plaza. The queue from the signalized intersection of Lynnfield Street & Summit Street seems to regularly back up well beyond the plaza entrances and exits. When not in queue, vehicles seem to travel much faster than would be expected, making it extremely difficult to turn out of the plaza, especially when taking a left hand turn. There are no visible lane markings, sidewalks shoulders, or curbs. Therefore, it is difficult to tell where the plaza entrances/exits/parking lot ends and the roadway begin. Perhaps this problem would be alleviated if it were clear as to where the road edge was and the parking lot began. This could be done by adding a white edge line on the roadway. Bollards and a chain could prevent motorist from entering or exiting the parking lot wherever they wish. Perhaps a one way entrance and one way exit would be beneficial at this location. A "RIGHT TURN ONLY" sign could be placed at the exit so that left turns with limited sight distance due to queuing are not made. Increased signage in general could aid motorist. Furthermore, perhaps a sign telling motorists not to block this entrance plaza would be beneficial for motorists traveling on Summit Street. Stop bars could also be used. Additionally, perhaps the signal at Lynnfield Street could be retimed to reduce the queues at this location.

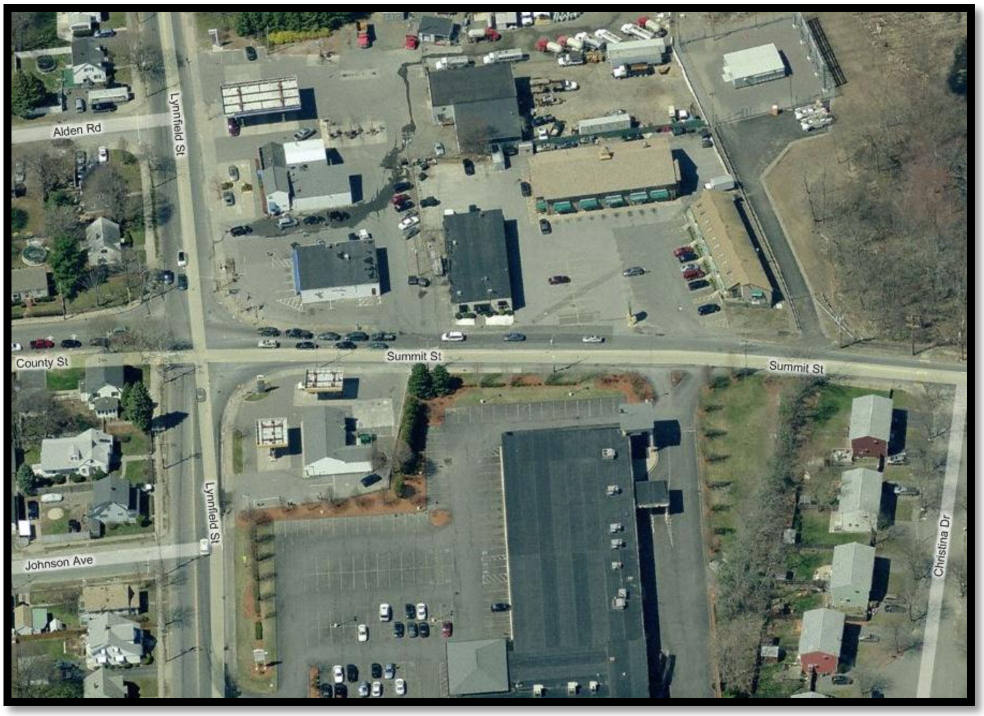


Figure 70. Roadway Segment 300255 Bird's Eye View


Figure 71. Roadway Segment 300255 Proposed Plaza Entrance

Figure 72. Roadway Segment 300255 Queue

Roadway Segment 396861 is located on Cranberry (U.S. Highway - Route 6) in Wareham, Massachusetts. It extends from Main Avenue Sean Circle. This segment is 0.2998 miles long and has an average daily traffic (ADT) of 20600 vehicles. In 2007 and 2008, there were a total of **12 drivers age 65+ and 17 drivers between the ages of 35-55** involved in crashes on this segment. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes on this segment is less than the statewide ratio of 1:4.76, this location has been identified as a location in which older drivers are overrepresented in crashes. Figure below depicts an ArcGIS snapshot view of the roadway segment which is highlighted in yellow with the locations along the segment in which older drivers were involved in crashes highlighted in light blue. [It should be noted that roadway segment 395712, also located on Cranberry Highway (U.S. Highway - Route 6) but west of roadway segment 396861, is in close proximity. This segment had an additional 4 older drivers involved in crashes in the same timeframe and therefore was also deemed a roadway segment with a high number of older drivers involved in crashes. As such, this segment will be examined in the field in conjunction with this road safety investigation. This segment is also highlighted in yellow in Figure 73; however, the locations along the segment in which older drivers were involved in crashes are shown in black.] All 12 older drivers involved in crashes on this roadway segment were involved in 2 vehicle crashes. Furthermore, 6 drivers were involved in angle crashes, 5 drivers were involved in rear-end crashes, and 1 driver was involved in a sideswipe same direction crash. The driver contributing code on the crash report form indicates that 4 drivers were faulted for not paying attention and 2 drivers failed to yield right of way. It should also be noted that 10 drivers were involved in property damage only crashes and 2 drivers were involved in non-fatal injury crashes. This roadway segment was chosen as a location in which a road safety investigation be conducted as it ranked **1 out of 8 for the age 65+ crash frequency method and 5 out of 23 for the age 65+ EPDO index method**.

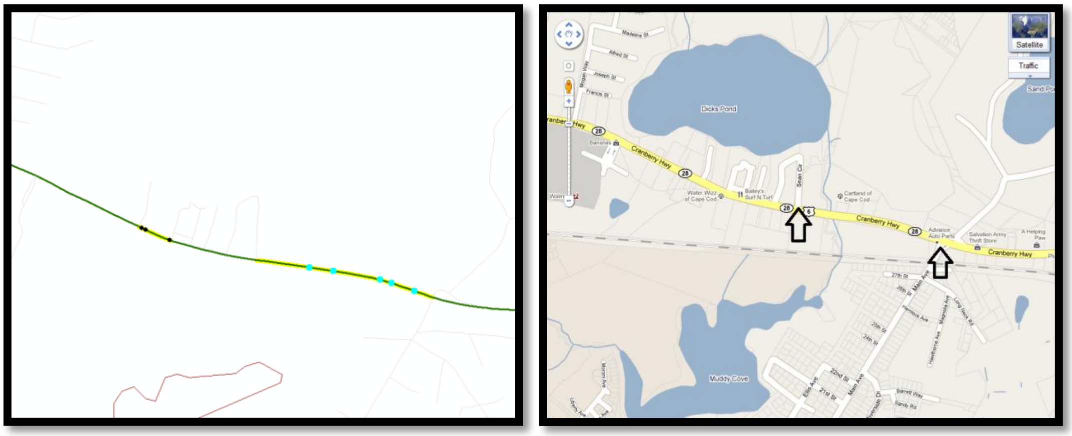
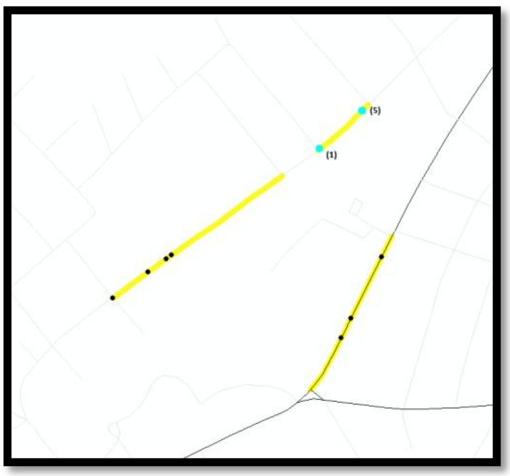


Figure 73. Roadway Segment 396861 ArcGIS and Google Maps

Roadway Segment 396861, located on Cranberry (U.S. Highway - Route 6) in Wareham, Massachusetts, is a 4 lane major roadway with a double yellow centerline. This roadway has confusing signs and signals that require quick decisions at relatively high speeds. There are a lot of businesses with a lot of advertising on the roadside. It seems there is too much to look at. It is likely that the road segment crashes are related to spillback from intersections. This location has access management issues as there are too many spots to turn in and out of. Many of these driveways could be condensed to the lights limiting the motorists turning in and out of driveways on the segment. A larger shoulder could aid in reducing rear-end crashes. Also, left turn lanes could aid in vehicles turning left into a driveway. It would be ideal to eliminate left turn movement out of driveways on this segment. If driveways cannot be condensed to signalized intersections, a raised median with reflectorized paint could prevent left turn movement. Alternatively, “RIGHT TURN ONLY SIGNS” could be installed at the driveways. There are small horizontal and vertical curves on and around this segment, however, further investigation would be required to see whether these meet the specified requirements for the recommendations in included in the *Older Driver Highway Design Handbook.*

Figure 74. Roadway Segment 396861 Street View

Roadway Segment 404165 is located on Linden Street in Wellesley, Massachusetts. It extends from Donazetti Street to Hill Top Road. This segment is 0.0741 miles long and has an average daily traffic (ADT) of 3000 vehicles. In 2007 and 2008, there were a total of **6 drivers age 65+ and 4 drivers between the ages of 35-55** involved in crashes on this segment. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes on this segment is less than the statewide ratio of 1:4.76, this location has been identified as a location in which older drivers are overrepresented in crashes. Figure 75below depicts an ArcGIS snapshot view of the roadway segment which is highlighted in yellow with the locations along the segment in which older drivers were involved in crashes highlighted in light blue. [It should be noted that roadway segment 404255, also located on Linden Street but south of roadway segment 404165, is in close proximity. This segment had an additional 6 older drivers involved in crashes in the same timeframe and therefore was also deemed a roadway segment with a high number of older drivers involved in crashes. This segment was only a high ranking segment in multiple methods. As such, this segment will be examined in the field in conjunction with this road safety investigation. This segment is also highlighted in yellow in Figure 75; however, the locations along the segment in which older drivers were involved in crashes are shown in black.] All 6 older drivers involved in crashes on this roadway segment were involved in 2 vehicle crashes. Furthermore, 4 drivers were involved in angle crashes while 1 driver was involved in a rear-end crash and 1 driver was involved in a sideswipe same direction crash. The driver contributing code on the crash report form indicates that 1 driver was faulted for not paying attention. It should also be noted that all 6 drivers were involved in property damage only crashes. This roadway segment was chosen as a location in which a road safety investigation be conducted as it ranked **3 out of 137 for the age 65+ crash rate method, 5 out of 179 for the age 65+ section rate method, and 3 out of 149 for the age 65+ 'average of methods' method**.



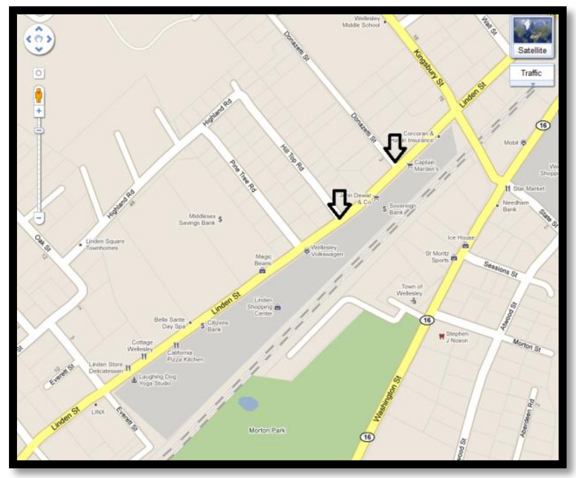


Figure 75. Roadway Segment 404165 ArcGIS and Google Maps

Roadway Segment 404165, located on Linden Street in Wellesley, Massachusetts, is a two lane roadway. The main problem area on this roadway segment seems to be the small Dunkin Donuts plaza which is really busy. Across from the entrance to this plaza, there is a left turn only lane for those wishing to turn onto Donazetti Street however the width does not really change and this seems unnecessary as it does not seem like too many people drive down that roadway, given that it is a "NO OUTLET". Also cannot see this lane is a turn only lane as it needs to be repainted and there are no shoulders. This is a very small section but has a lot going on. Additionally, the roads are narrow and the intersections are small. People are exiting Dunkin Donuts right across the intersection. Increased signage or perhaps a flashing yellow beacon could be implemented at the Dunkin Donuts plaza. Perhaps the left turn lane for Donazetti Street could be converted to a right turn lane for the Dunkin Donuts plaza. Perhaps this entrance could be moved further away from the intersection. Given that this plaza has a second entrance/exit slightly north of this location, perhaps this one could be an "ENTRANCE ONLY" and the other an "EXIT ONLY".

Figure 76. Roadway Segment 404165 “NO OUTLET” Warning Sign

Figure 77. Roadway Segment 404165 Dunkin Donuts Plaza Entrance

Figure 78. Roadway Segment 404165 Proposed Plan for Plaza

Roadway Segment 440664 is located on Gold Star Boulevard (State Route 12) in Worcester, Massachusetts. It extends from West Boylston Terrace to the driveway of Harr Chrysler Jeep Dodge. This segment is 0.0338 miles long and has an average daily traffic (ADT) of 24100 vehicles. In 2007 and 2008, there were a total **of 6 drivers age 65+ and 12 drivers between the ages of 35-55** involved in crashes on this segment. Since the ratio of drivers age 65+ involved in crashes to drivers age 35-55 involved in crashes on this segment is less than the statewide ratio of 1:4.76, this location has been identified as a location in which older drivers are overrepresented in crashes. All 6 older drivers involved in crashes on this roadway segment were involved in 2 vehicle crashes. Furthermore, 3 drivers were involved in angle crashes and 3 drivers were involved in rear-end crashes. It should also be noted that 5 drivers were involved in property damage only crashes while 1 driver was involved in a non-fatal injury crash. This roadway segment was chosen as a location in which a road safety investigation be conducted as it ranked **4 out of 175 for the age 65+ crash density method and 3 out of 174 for the age 35-55 crash density method.**

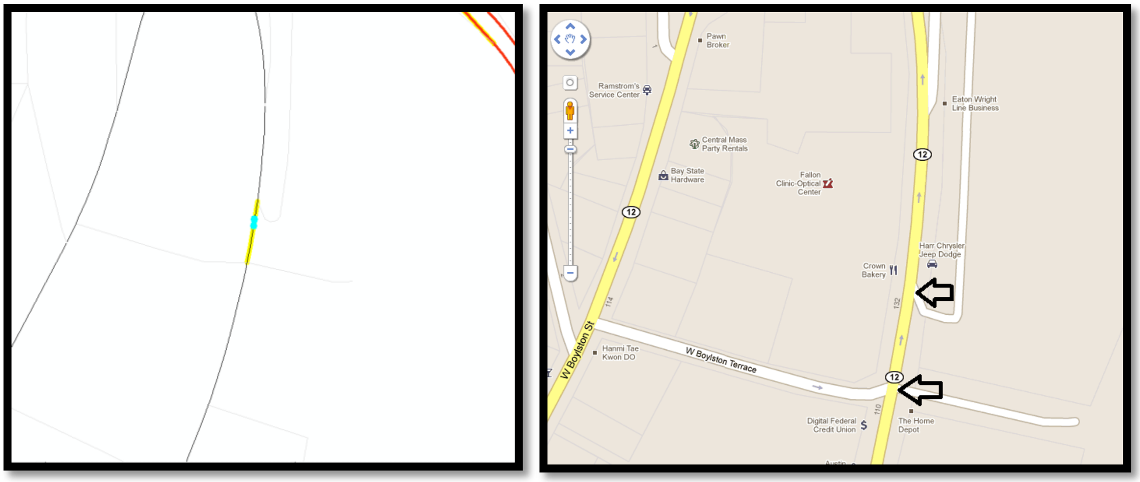


Figure 79. Roadway Segment 440664 ArcGIS and Google Maps

Roadway Segment 440664, located on Gold Star Boulevard (State Route 12) in Worcester, Massachusetts, is a one way four lane segment. Given the small nature of this segment, it can almost be regarded as a single intersection. This intersection is a large signalized intersection. This area is very busy and there is a lot going on to look at. The lane markings are hard to see as they are faded. There is a lot of traffic and the lanes appear narrow. The merge at the exit of Home Depot & Panera Bread is difficult to maneuver and there is limited sight distance as you turn the corner in which there are immediately other driveways in which cars may be exiting or stopped to pull into in either the right lane or the left lane (the same is true as you turn onto Gold Star Boulevard from West Boylston Terrace). Larger shoulders could aid in reducing rear end crashes on both side of this roadway. Perhaps one lane could be eliminated to make this change. The curb radius at Home Depot could be reduced to slow people down as the turn onto or off of this busy driveway.

Figure 80. Roadway Segment 440664 Satellite View

Figure 81. Roadway Segment 440664 Street View

Relationships between Methods(s) Used and Proposed Countermeasures –Segments

Next, relationships between the method(s) used to identify the high crash location and the recommended countermeasures proposed for the specified location were identified. This can provide transportation professionals with a list of countermeasures to consider depending upon which method was utilized in identifying the specified location.

Frequency Method (Age 65+ and Age 35-55) and EPDO Index Method

Observed correlations between locations

- Major Arterial Roadway with relatively high speeds
- A relatively high number older drivers involved in rear-end crashes
- High volume (ADT = 11,600 & 20,600, 15,300, & 19,600)
- Relatively Large in length (Greater than or equal to 0.3 miles)
- Several driveways used to access businesses
- A lot for the driver to look, drivers are required to make quick decisions
- Small shoulders
- Changing lane configurations
- No median or barrier separation the travel directions (painting in some areas)
- Possible glare issues
- Queues from nearby intersections blocking driveways to businesses

Possible Countermeasures to consider when using the age 65+ frequency method or age 65+ EPDO index method to identify high crash locations for older drivers

- Larger shoulders to reduce rear-end crashes
- Raised reflectorized medians or barriers to separate directions of travel
- Prohibited left turns out of driveways with "RIGHT TURN ONLY" signage
- Merge driveways or condense to signalized intersections
- Decrease business advertising and signage
- Repave roadways, fill potholes, and repaint pavement markings

Density Method (Age 65+ and Age 35-55), Rate Method (Age 65+ and Age 35-55), Section Rate Method (Age 65+ and Age 35-55), Severity Index Method, EPDO Rate Method, and the 'Average of Methods' Method

Observed correlations between locations

- Unusually small roadway segment and/or unusually low volume
- Crashes often isolated to one intersection and/or driveway entrance and/or exit or a specific spot
- Road appears narrow
- Faded pavement markings
- No signals and minimal signage
- Small shoulders
- Possible glare issues

Possible Countermeasures to consider when using Density Method (Age 65+ and Age 35-55), Rate Method (Age 65+ and Age 35-55), Section Rate Method (Age 65+ and Age 35-55), Severity Index Method, EPDO Rate Method, or the 'Average of Methods' method to identify high crash locations for older drivers

- Larger shoulders to reduce rear-end crashes
- Prohibited left turns out of driveways with "RIGHT TURN ONLY" signage
- Increased signage (i.e. warning and regulatory signs)
- Flashing yellow beacon on major roadway at plaza entrances where crashes seem to be concentrated
- Repave roadways, fill potholes, and repaint pavement markings
- Add pavement markings (especially edge lines to make a distinction between the roadway and parking lots or driveways
- Ban parallel parking on segment during peak hours or when crashes are most common and ensure that parking is not creating sightline restrictions at plaza driveways
- Reduce the number of driveways from a single plaza and/or make one an entrance only and one an exit only

When applying each method to the control group (age 35-55) for the roadway segments, the same results seem to be generated. This is because the results of these methods are determined by either the segment length or the average daily traffic or a combination of the two which remain constant when the age group is changed. It should be noted that different results may be obtained between age groups for those segments which to not have an unusually small segment length or average daily traffic.

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 can vary greatly for this method, however in the analysis herewith; methods in which the average daily traffic and/or segment length are a factor outweigh the methods in which they are not a factor. As a result, the results correlate with methods which use the segment length and/or ADT.

Evaluation of Countermeasures

The AASHTO Strategic Highway Safety Plan works to decrease fatalities on the nation's roadways through cost effective countermeasures which have proven to minimize crashes. Volume 9 of the NCHRP Report 500: A Guide for Reducing Collisions Involving Older Drivers provides strategies which can be implemented to reduce the number of crashes involving older drivers. This report provides a description of each strategy and the associated implementation timeframe and relative cost of each strategy. This will be used to evaluate several of the countermeasures proposed at the ODHCL's. It should be noted that there are proposed countermeasures which are not included in this report and therefore they were not evaluated. Table 29 presents the timeframe for implementation and relative cost to implement and operate for each strategy relating to the improvement of the roadway and the driving environment to better accommodate the special needs of older drivers (13).

Table 29. Evaluation of Proposed Countermeasures (13)

Strategy	**Timeframe for Implementation**	**Relative Cost to Implement and Operate**	**Proficiency**
Provide advance warning signs	Short (less than 1 year)	Low	Tried
Provide advance guide and street name signs	Short (less than 1 year)	Low	Tried
Increase the size and letter height of roadway signs	Short (less than 1 year)	Low	Tried
Provide all-red clearance intervals at signalized intersections	Short (less than 1 year)	Low	Tried
Provide more protected left turn signal phases at high volume intersections	Short (less than 1 year)	Low	Tried
Provide offset left-turn lanes at intersections	Medium (1 to 2 years)	Moderate to High	Tried
Improve lighting at intersections, horizontal curves, and railroad grade crossings	Medium (1 to 2 years)	Moderate to High	Tried
Improve roadway delineation	Short (less than 1 year)	Low	Tried
Replace painted channelization with raised channelization	Medium (1 to 2 years)	Moderate	Proven
Reduce intersection skew angle	Medium (1 to 2 years)	Moderate to High	Tried
Improve traffic control at work zones	Medium (1 to 2 years)	Low	Tried

In some instances the timeframe for implementation and the relative cost to implement and operate each strategy will vary depending on the agency's procedures, required right-of-way, the number of stakeholders, policies and legislative issues, or controversial situations. The costs are relative to one another as it is known that what is low cost for one agency might be high for another. Furthermore, proficiency is based on the extent to which evaluations have proven their effectiveness. Many strategies have not been evaluated extensively and therefore caution should be taken when considering implementation of the strategy. To aid with this, the strategies have been labeled as proven (P), tried (T), or experimental (E). A detailed explanation of the meaning of each are included in NCHRP's report (13).

5.0 PROGRAMMATIC DETECTION OF OLDER DRIVER HCL's

Although the manual analysis presented in this paper has many advantages, there are many motivations for alternative detection of older driver high crash locations through the development of clustering programs. These include a way to identify high crash locations faster and with unbiased expectations. Additionally, trends invisible to visual/manual clustering may be discovered as this type of analysis would not require the separation of drivers involved in crashes at an intersection from those involved in crashes on a roadway segment. Furthermore, the roadway inventory file and the ability to link this file with crash data would not be required.

Theory

Programmatic detection of high crash clusters requires an algorithm that can automatically group crash data locations and order the groups and provide a means to order groups according to observed risk. This developed method uses a k-means clustering algorithm to partition crash data into clusters using the 2 -dimensional geographic projection data (x and y coordinates) associated with each driver involved in a crash in the dataset. Since k-means algorithms require the final number of clusters (k) as an input, the clustering algorithm was paired with a hill climbing algorithm to optimize the clustering for a desired average cluster diameter. The cluster diameter was defined as the greatest Euclidean distance (in meters) between any two crash locations in a cluster. If a cluster consists of a single crash location, its diameter is 0 meters. The algorithm used is as follows for an initial diameter *D*, *ERROR_D*, and n crash data points:

Initial values are:
d_max = (1 + ERROR_D) * D
d_min = (1 - ERROR_D) * D
k_max = 0.5 * n
k_min = 2
k = 0.5 * k_max

1. Cluster the data by into *k* clusters
2. Calculate the average diameter *d* of the clustering
3. Select a *k'* for *d* and repeat with *k=k'*

The value of k' after each iteration is defined as:

d > d_max → k' = (k_max – k)/2, k'_min = k
d < d_min → k' = (k – k_min)/2, k'_max = k
d_min <= d <= d_max → routine finished

This algorithm is not guaranteed to produce the optimal clustering because the k-means algorithm is non-deterministic for k and the entire search space is not evaluated.

Implementation

The algorithm is implemented in the Python programming language and uses the Pycluster library to perform the clustering step (16). The Pycluster library was developed for bioinformatics applications at the University of Tokyo, but can be used to cluster 2-dimensional crash location data.

The crash data is read into the program from a comma separated value (CSV) file output from ARC GIS and output data is saved as a CSV file consisting of the input rows and three new fields: CLUSTER_ID, CLUSTER_SIZE, and CLUSTER_DI. CLUSTER_ID represents the cluster to which each driver involved in a crash was assigned in the final clustering. Data for the same cluster is determined by selecting all crashes from the output data having the same cluster id. The CLUSTER_SIZE field represents the total number of crashes in the cluster to which a specific crash data entry belongs while the CLUSTER_DI represents the diameter of the cluster in meters, allowing for density calculations to be computed using the output table. A density measure of the density of drivers in crashes per cluster would make it easier to directly compare the significance of clusters in the result.

The application is run from the command line and provided with the input data set and a desired average cluster diameter in meters. The application then runs until the calculated average cluster diameter is within +/- 10% of the desired diameter at which point the output CSV file is generated. Diagnostic information is generated for each clustering iteration including the k value used and the time required to complete the clustering. Since the k-means algorithm is non-deterministic for a given k and input data set, successive runs of the application on the same data set will produce different clusterings.

The application in conjunction with an ArcGIS platform, which offers spatial referencing capabilities and graphical displays, a more effective crash analysis program, can be realized

Improvements

While the average cluster diameter is used to optimize the number of clusters in the result, it does not account for variance in the calculated clusters. In addition to optimizing for a desired average diameter, the application could attempt to minimize the variance in the diameter of the clusters. The non-deterministic properties of the k-means algorithm could be used to minimize the variance by re-clustering for a given k to produce a clustering with a lower variance in the average cluster diameter.

The algorithm developed here is relatively independent of the specifics of the task being performed. More accurate clusters might be achieved by taking into account the additional data provided with crash data. Clusters could potentially be limited to intersections or specific road segments using the road segment associated with each crash. The current implementation clusters crashes without regard to the road segment type on which the crash occurred. Consequently, a cluster may consist of crashes occurring on limited access highway segments and unrelated crashes occurring on nearby local road segments, leading to ambiguity as to the significance of the generated cluster. Filtering for crashes by road segment type could be performed at the input data or within the application to potentially reduce artificially significant clusters.

6.0 SUMMARY & 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.

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