A REDUCTION IN NONFATAL-INJURY MOTOR VEHICLE CRASHES WITH ANTI-ICING TECHNOLOGY

James Mahoney*
Connecticut Transportation Institute
University of Connecticut
270 Middle Turnpike Unit 5202
Storrs, Connecticut 06269-5202
Tel: 860-486-9299
Fax: 860-486-2399
Email: james.mahoney@uconn.edu

Donald A. Larsen, PE
Connecticut Transportation Institute
University of Connecticut
270 Middle Turnpike Unit 5202
Storrs, Connecticut 06269-5202
Tel: 860-486-5400
Fax: 860-486-2399
Email: larsen@engr.uconn.edu

Eric Jackson, PhD
Connecticut Transportation Safety Research Center
University of Connecticut
270 Middle Turnpike Unit 5202
Storrs, Connecticut 06269-5202
Tel: 860-486-8426
Fax: 860-486-2399
Email: e.jackson@engr.uconn.edu

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*Corresponding Author

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ABSTRACT

Although there are several published papers and studies that find adverse weather conditions contribute to motor vehicle crashes and have an overall negative effect on highway safety, there do not appear to have been results published for an entire network, such as a state highway system, demonstrating the positive effects of winter maintenance anti-icing policies on safety. Following a decision in 2005/2006, the Connecticut Department of Transportation (CTDOT) converted from deicing to anti-icing policies. In this paper, aggregated motor vehicle crashes with nonfatal injuries are analyzed graphically to determine if winter weather safety was affected by CTDOT's switch from deicing using a sand and salt mix to anti-icing procedures including a switch to all salt. A survey of the states surrounding Connecticut provided evidence that CTDOT applies winter deicer chemical types and quantities in a similar manner to its neighboring states. This Connecticut study concludes that crashes with nonfatal injuries during winter seasons, in all kinds of weather and road conditions, declined by 19.2 percent between seven winters with sand-salt (7:2) mix (1999/2000-2005/2006) and seven winters of salt-only (2006/2007-2012/2013); and also that the same type of crashes that occurred when roads were snow/slush or ice covered declined by 33.5 percent. Also, there was an immediate additional reduction in nonfatal crashes with injuries after CTDOT converted to anti-icing in 2006/2007. Even considering the value of the increase in safety technology employed by modern vehicles, it appears that anti-icing likely reduces the amount of time that roads are slippery, thus prompting a reduction in serious crashes.

Keywords: Anti-icing, Deicers, Salt, Sand, Snow, State Highway Network, Motor Vehicle Crashes, Winter Maintenance, Winter Weather Crashes

INTRODUCTION

The Federal Highway Administration (FHWA) estimates that "*each year, 24 percent of weather-related vehicle crashes occur on snowy, slushy or icy pavement and 15 percent happen during snowfall or sleet. Over 1,300 people are killed and more than 116,800 people are injured in vehicle crashes on snowy, slushy or icy pavement annually*" (*1*) in the United States. Winter maintenance policies for roadways have the potential to significantly influence these crash statistics, particularly for Snow Belt states.

Connecticut is one of several northeastern states that has been working toward making winter weather driving safer via the adoption of anti-icing policies and strategies. From 2006 through the present, the Connecticut Department of Transportation (CTDOT) has been proactive in transitioning from roadway deicing to a strategy of anti-icing (*2*), which includes:

- Elimination of the use of sand;
- Pretreating with sodium chloride brine solution;
- Pre-wetting of solids (salt) with a solution of calcium chloride or magnesium chloride;
- Making plans to increase the number of Road Weather Information Systems (RWIS); and,
- Experimenting and conducting pilot trials with salt slurry generators (*3*).

As a result of Connecticut's winter maintenance policy transition, there is evidence of a reduction in winter weather nonfatal injury motor vehicle crashes on state-maintained roadways. This research paper presents the data and information that leads to this conclusion. It provides an example of the impact of proactive government actions on safety.

The following section provides a brief summary review of literature on the effects of adverse weather on traffic volumes, speeds, crashes and injuries. The next section describes the methodology followed in construction and analysis of the crash data set from the Connecticut Crash Data Repository (CTCDR). This is followed by a summary of findings regarding the use of deicers in Connecticut relative to surrounding northeastern states. Next is a graphical analysis of motor vehicle crashes with nonfatal injuries that occurred during the winter seasons. The final sections of the paper provide a summary of findings and conclusions regarding motor vehicle crashes on CTDOT-maintained roads during winter weather.

LITERATURE REVIEW

Studies were found (*4, 5, 6*) that evaluate the relationship between adverse winter weather and traffic volumes and/or speeds. There is documented evidence that, at least during major winter weather events, there is a reduction in travel, which can have a negative effect on the economy, yet from a positive perspective, reduce the severity of crashes due to the lower levels of traffic and slower travel speeds. However, even with reduced traffic and travel speeds, due to reduced traction during times of slippery surface conditions, coupled with lowered visibility, a significant increase in the vehicle crash rate typically occurs.

In Alberta, Canada, Datla and Sharma (*4*) studied highway traffic volumes versus cold temperatures, snowfall amount, and a combination of both, as well as the timing during the winter season when snowfall occurs. They concluded that there is a 1 to 5 percent reduction in traffic volume per centimeter of snow, dependent upon the temperature occurring at the time of

snowfall. They also found the largest impact on traffic occurs during the earliest season snows. Knapp and Smithson (*6*) looked at traffic volumes on Iowa interstate highways for 64 winter storms of at least 4-hour duration and snowfall rates of 0.20 in/hr. and greater. The average traffic volume reduction was 29 percent, varying from 16 to 47 percent depending upon total snowfall and wind gust levels. Maze et al (*5*) performed a literature based review and summary of the impact of weather on traffic demand (deferring or eliminating trips), traffic flow (volume, speed and density) and traffic safety (crash rates per mile.) A reduction in traffic volumes due to snow was found to be highly variable, ranging from 7-80 percent depending on type of traffic (commercial, commuter or long distance) and weather severity. Specifically, in the area of safety it is reported in (*5*) that "*the increased risk of a crash while traveling during severe winter weather is greater than the risk brought by behaviors that state governments already have placed sanctions against, such as drunk driving or speeding"* (*5,* p. 175).

A study by Qiu and Nixon (*7*) found that all types of crashes (fatal, nonfatal injury, and property damage only (PDO)) exhibit some level of increase in crash rate during rain or snowfall. The average percent change in overall crash rate during snow is reported at 84 percent. Hierarchy meta-analyses were conducted to assess the extent of motor vehicle crash pattern changes between 1950 and 2005. The percent change of crash rates during snowfall indicates a decreasing tendency over the decades. One possible explanation given in (*7*) for this finding is that winter maintenance methods and technologies have improved, particularly with the introduction of anti-icing. A second study by Qiu and Nixon (*8*) produced a probability of crashes in certain adverse weather conditions (primarily snow, wind, low visibility and low temperature) and the effects of winter maintenance (plowing, sanding and salting) in mitigating crashes in Iowa. The results of the 4-year study, which used data from Road Weather Information Systems (RWIS), DOT crash records, automated traffic recorders and automated weather systems, is "*that plowing activities indirectly reduce injury probability by 24.2% and PDO probability by 23% through improving road surface conditions for interstate or primary highways. Similarly chemical application reduces injury by 33.3% and PDO by 17.8 %,…*"(*8*). Use of sand and abrasives alone reportedly did not produce similar results (*8*).

In 2005, Zhirui Ye et al. (*9*) used an artificial neural network to investigate and evaluate the effects of winter maintenance chemicals on road safety and applied the model to two highways in Idaho. A benefit/cost analysis produced a positive benefit/cost ratio of 5.5-7.0, due to estimates that winter chemicals if not applied would result in 200 additional crashes at the study sites. Another study by David Eisenburg et al (*10*) used crash data from the Fatality Analysis Reporting System (a nationwide census) and the NHTSA's State Data System for a subsample of 17 states during the 1990s to estimate the effects of snowfall on PDO crashes, crashes with injuries and fatal crashes. A total of 1.4 million fatal crashes, 13.5 million nonfatal injuries only crashes and 22.9 million PDO crashes were available for the 17 states. However, Eisenburg (*10*) did not account for or consider the level or variability of highway winter maintenance provided in the various states, presumably on the assumption that similar efforts are applied everywhere to mitigate the effects of snowfall on travel. During the period of the dataset (1975-2000) many states were using deicers and abrasives alone, while a few were in various stages of conversion to anti-icing. Since 2005 it has become widely recognized that anti-icing produces a greater impact on travel than deicing alone. In fact, a survey of 26 states and Canadian provinces in April 2014 performed by Cui and Shi (*11*) indicated that many states had converted and found

many benefits to anti-icing that were not recognized in a similar survey of 15 states and provinces that had been performed by the same organization in 2005. The anti-icing benefits include achieving bare pavement quickly and making snowplowing much easier (*11,* p. 12).

Safety benefits of anti-icing strategies have been reported in several states. According to an online brochure (*12*) published by the Pacific Northwest Snowfighters Association "*Snow and ice control methods have had a major, positive impact on traveler safety. ...During a twelve-year study involving anti-icing strategies on the interstate system in the Denver metro area, Colorado saw an average decrease of 14% in snow and ice related crashes*"(*12,* pp. 1-2).

With the exception of one study in Idaho (*13*), where the costs of Idaho Transportation Department RWIS stations were compared to the benefits of reduced crashes, no literature was found on studies that establish that an agency's winter maintenance policy has directly affected a change in safety, with a resultant reduction in vehicle crashes on a statewide network of roads. This Connecticut study shows that such a reduction in statewide crashes did occur in Connecticut following a decision in 2005/2006 to eliminate the use of sand and abrasives and to implement anti-icing practices, including pre-treating roadways, pre-wetting deicers and upgrading to state-of-the-art winter maintenance equipment.

BACKGROUND

This paper illustrates the effect that advances in winter weather maintenance practices and policies have had on road safety in Connecticut. Using aggregated motor vehicle crash data for the state-maintained roadway network, the results can assist in justifying state DOT expenditures for policies that include greater emphasis on utilizing state-of-the-art technology such as anti-icing, RWIS and modern plow and spreading equipment. The research presented in this paper is based on graphical analyses of 117,890 motor vehicle crashes with nonfatal injuries that occurred on Connecticut state-maintained roadways from 1999-2013. The crash information presented in this paper was part of a larger study conducted in 2015 in partnership with the Connecticut Academy of Science and Engineering (CASE) at the invitation of the CTDOT in response to legislation enacted by the Connecticut General Assembly (*3*).

METHODOLOGY

Data Sources

The CTCDR, funded by the CTDOT and maintained by the Connecticut Transportation Institute at the University of Connecticut (UConn), was used to perform crash analyses for this study. The CTCDR contains data from all motor vehicle crashes that occurred in Connecticut on both the 3,734 centerline miles of state-maintained and the 17,339 centerline miles of municipal-maintained roadways (*14*). The crashes recorded in the CTCDR involve property damage and personal injuries and/or fatalities that are reported and investigated by a local or state law enforcement agency. Information on approximately 1.6 million motor vehicle crashes for the years 1995 through 2014 currently resides in the CTCDR. The CTCDR crash data can be retrieved, sorted and summarized by any number of attributes, such as location (route, town, and region), collision type, date, time, weather condition, road surface condition, light condition and others (*15*).

The FHWA Road Weather Management program defines weather-related crashes as "*those that occur in the presence of adverse weather (including rain, sleet, snow, fog, rain/fog, and sleet/fog) and/or slick pavement (wet, snowy/slushy, and icy)*" (*1*). Paul Pisano of FHWA reported in (*16*, p. 3) that "*Slick pavement conditions are very dangerous, even when there is no precipitation or fog. Over one-third of weather related crashes occur on slick pavement in the absence of adverse weather.*" It should be noted that in the FHWA study wet pavement (representing 73 percent of adverse weather crashes) is included in the reported slick pavement category. This Connecticut study, however, only includes analysis of motor vehicle crashes that reportedly occurred on pavement with conditions of snow/slush or ice. Wet pavement condition crashes (as well as dry) are excluded from this analysis, with the exception that the long-term trends of total crashes (which include wet and dry) are discussed briefly. The ambient weather conditions, however, were not restricted, such that a crash occurring under any reported weather condition from clear to snow to rain to fog was included in the analysis, as long as the pavement conditions were recorded by the investigating law enforcement officer as snow/slush or ice. Therefore, many of the crashes occurred during winter weather events, but others occurred after the event and prior to the road returning to bare pavement. Crashes occurring as a result of a re-freeze or from frost are also included in the analysis, if the surface was reported to be snow/slush or ice.

This study uses only crashes that occurred on the state highway system, which includes interstates, US routes and Connecticut state routes. Excluding municipal roads eliminates consideration of differential winter maintenance policies and procedures deployed within Connecticut's 169 cities and towns. The winter maintenance policies applied to state roadways are fairly consistent throughout Connecticut, with the primary variables being traffic levels and local climatic conditions. Finally, to ensure enough crash data for analysis, retrieved aggregated crashes are analyzed statewide rather than by geographic region or CTDOT Maintenance District.

Weather data for this study (number of winter weather events and average annual snowfall) were obtained from CTDOT, which monitors and records snowfall at 26 locations throughout Connecticut for every winter weather event. CTDOT categorizes a winter weather event as either a storm or an activity. Activities typically last less than six hours and involve less than 50 percent of the workforce. Storms are of longer duration with more than 50 percent of the snow and ice control workforce activated.

Vehicle miles travelled (VMT) data are not included or analyzed for this study. Such data are estimated by CTDOT as a daily and annual average for the network. However, they are not available for the network based on weather conditions. As reported in the literature, VMT likely varies between periods with storm events and non-storm events. Also, as mentioned in the literature review, other studies have documented traffic volume reductions during snow events, particularly during major storms. Without the VMT, only the crash frequency (actual number of crashes) rather than the crash rate is presented for the winter weather event crashes. The number of crashes during comparable periods with dry pavement is not included in this analysis. Therefore, the only information that can be gleaned from the presented datasets is the variation of crashes occurring during winter seasons and under snow/slush and ice surface conditions over the 14-year period. Since it is reported by others (*7*) that winter weather crashes overall have

been declining over the long-term, it is possible that some of the decline in crashes seen in the dataset is due to other factors such as improvements in vehicle technology, law enforcement, and better trained drivers.

An obvious benefit of anti-icing (as opposed to sanding and deicing alone) is the reduction of snowy/slushy and icy surface conditions. That is to say, the amount of time when snow/slush or ice occurs on the pavement during each weather event, as well as the total during the year, should be significantly reduced due to anti-icing efforts, which could be the single biggest factor in the reduction of crashes found in this study. CTDOT's current anti-icing strategy leads to less snow and/or ice bonding to the road surface and easier removal of snow by plowing (*2*). In addition, the chemicals applied before or at the early stage of a winter weather event make ice formation below the snow layer less likely. The reduction in ice formation provides more traction (less slippery road conditions) and, in theory, should lead to fewer motor vehicle crashes.

Amount of Salt Usage

All deicing chemicals have potential negative issues associated with them, such as adverse environmental impacts, high cost and/or the potential for corrosion to certain materials used in infrastructure and motor vehicles. A survey of surrounding northeastern states performed in (*3*) during 2015 provides a comparison benchmark for deicer use in Connecticut. State transportation agencies in Connecticut, Maine, Massachusetts, Rhode Island, New York, New Jersey, New Hampshire and Vermont were surveyed. Connecticut fares well among the seven nearby states, as far as chlorides (salt) use is concerned. In comparison with the surveyed northeastern states, where average annual total tons of chlorides applied ranged from 12.5 to 31.1 tons per lane-mile for winter seasons 2009/2010 through 2013/2014, CTDOT's 14.2 total chloride tons placed per lane-mile ranks on the low end for salt application — only Maine Department of Transportation (MaineDOT) and Vermont Agency of Transportation (VTrans) had lower application rates for total chlorides per lane-mile. However, because CTDOT proactively pre-wets nearly all solid sodium chloride to keep it from bouncing off of the road and initiate faster melting, the 87 gallons per lane-mile per season of liquid magnesium chloride solution (and previously liquid calcium chloride solution) applied by CTDOT places Connecticut on the higher end of liquid treatment applications relative to surrounding states, just below the usage on a per lane-mile basis for New Jersey Department of Transportation (NJDOT). The surveyed states use various blends of liquid and solid chemicals, which makes direct comparison between states somewhat difficult. In addition, the climate between and within each state varies significantly. The winter maintenance policy and level of service provided in each state also differs, producing variations in winter maintenance procedures.

ANALYSES

Effect of Salt Usage on Vehicle Crashes

It was determined that motor vehicle crashes involving nonfatal injuries would be the best metric to use for gauging the effect of CTDOT winter maintenance operations on highway safety. It is positive to note that when driving is compromised by snow/slush or ice conditions, the number of crashes involving fatalities is typically very small. Due to the small sample size, fatal crashes are not included in the analysis. PDO crashes are also excluded from the analysis. During winter weather events that arrive abruptly, law enforcement personnel are forced to prioritize

their response among the many crashes that can occur in a relatively short period of time. Crashes involving injuries typically receive the most attention. Thus, even though PDO-type crashes are much more prevalent than crashes with injuries, it is believed that the information recorded about winter-weather PDO crashes would tend to be less reliable, particularly during those periods when hundreds of crashes occur over a short timeframe.

For general reference, a plot of *all motor vehicle crashes involving nonfatal injuries only* on Connecticut state-maintained roadways (247,988 crashes) over the 14 calendar years from 2000 through 2013 shows that there was a steady decline in crashes nearly every year (Figure 1). The vehicle crashes plotted in Figure 1 occurred under all possible pavement surface conditions, i.e., dry, wet, snow, slush, ice, sand, mud, dirt or oil, other or unknown. Crashes occurring under all weather conditions are also included in this data presentation (Figure 1).

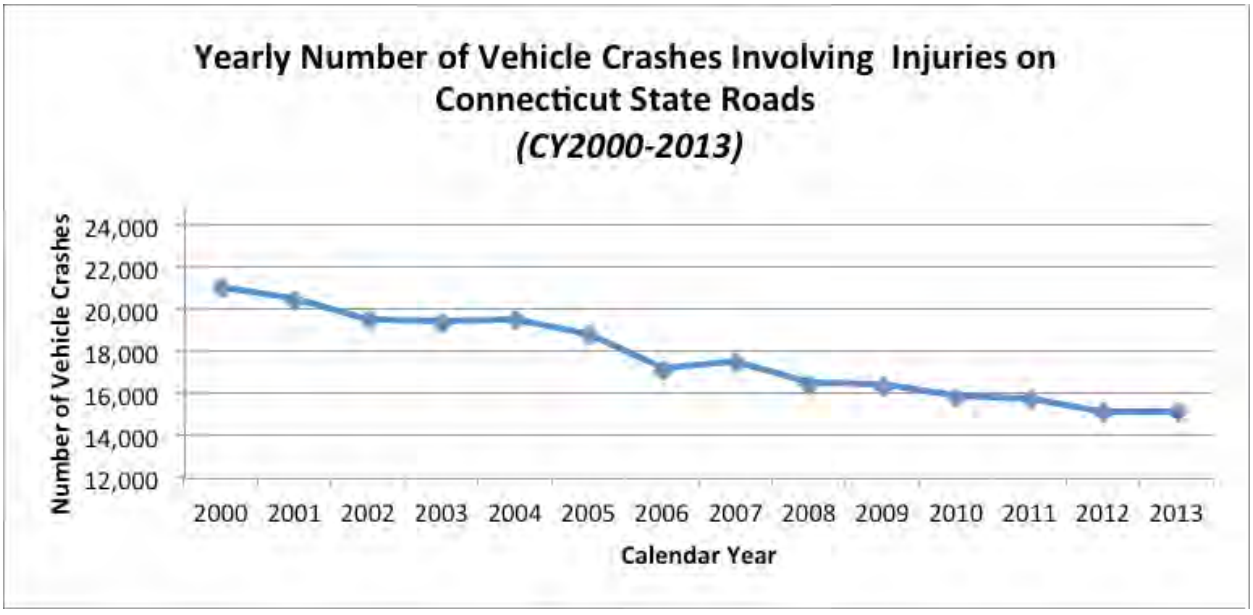

FIGURE 1 Yearly number of motor vehicle crashes involving nonfatal injuries on Connecticut state-maintained roads (Calendar years 2000-2013).

A similar plot of *motor vehicle crashes involving nonfatal injuries only and occurring during the winter season only*, defined in this study as November 1st through April 30th, also shows a significant decline over time, but with a notable step downward after implementation of anti-icing strategies during the winter season of 2006/2007 (Figure 2). The 117,890 winter season crashes plotted in Figure 2 are for the 14 winters of 1999/2000 through 2012/2013 extracted from the CTCDR using the following attributes:

- Months of November, December, January, February, March, April only
- State routes, interstate routes, US routes (no local roads)
- Injury crashes only (No property damage only and no fatal crashes)
- Weather conditions = ANY
- Surface Conditions = ANY (wet, dry, snow/slush, ice, sand, mud, dirt or oil, other or unknown)
- All other attributes such as contributing factors, collision types, light conditions, etc. = ANY.

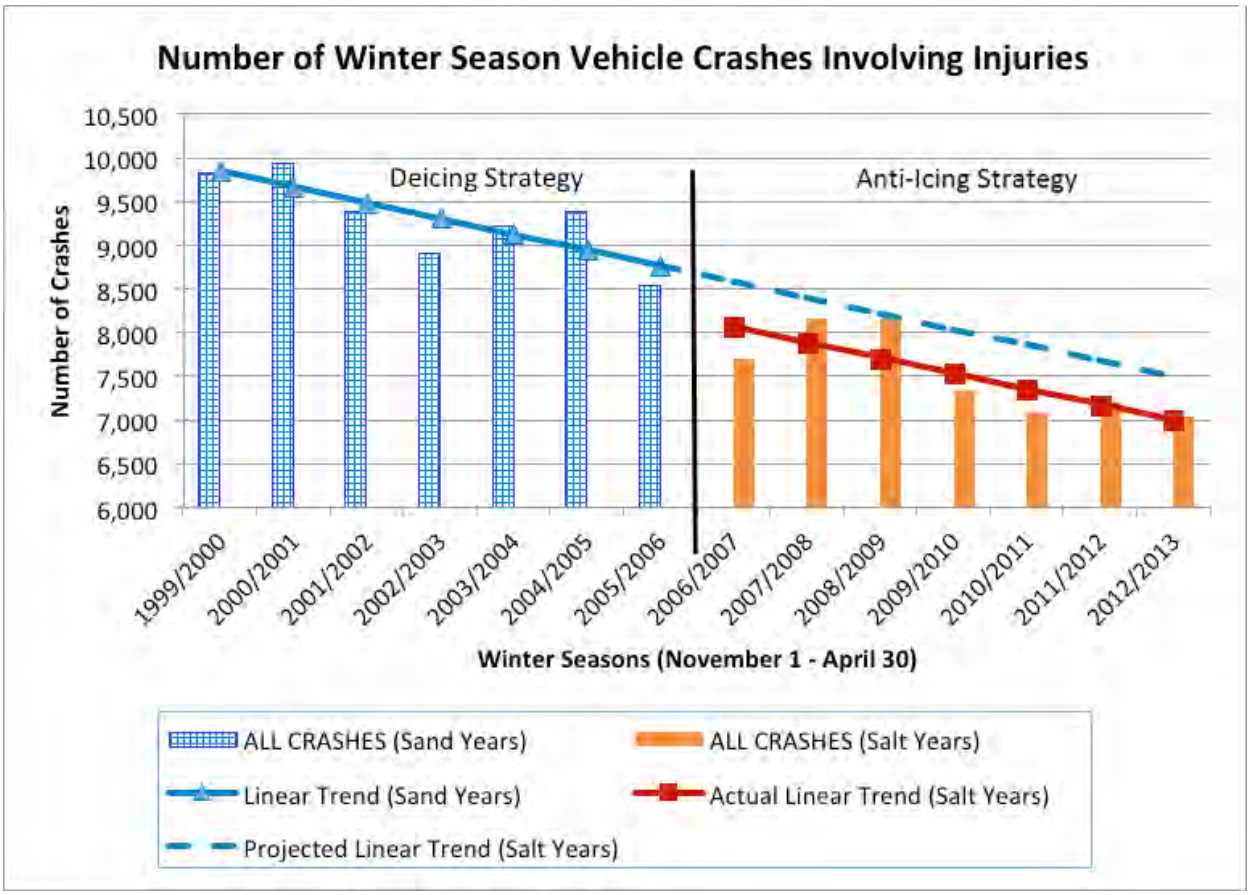

FIGURE 2 Winter season motor vehicle crashes involving nonfatal injuries (1999/2000-2012/2013).

Linear trend lines for both the deicing strategy years when sand and salt were used in a 7:2 ratio (seasons 1999/2000-2005/2006) and the anti-icing strategy years when only salt (little or no sand) was used (seasons 2006/2007-2012/2013) are included in Figure 2.

A third plot was developed for *winter season motor vehicle crashes with nonfatal injuries only that occurred only when the road surface was reported as snow/slush or ice covered* (Figure 3). This graph shows a significant year-to-year variability of crashes with injuries. The data indicate that the number of vehicle crashes involving injuries on surface conditions of snow/slush or ice for the period is 12,199, with roughly 200-1,400 crashes per winter season. A linear trend line for the deicing strategy period is superimposed on the graph in Figure 3, as well as projected forward through the anti-icing years. A second linear trend line is placed over the salt only years (anti-icing period).

A single factor analysis of variance (ANOVA) was performed on the data plotted in both Figures 2 and 3. The ANOVA shows that there is likely a statistically significant difference in anti-icing crashes compared with the deicing crashes, i.e., between the two periods of time, 1999-2005 and 2006-2013. The null hypothesis, that the means of the two datasets are equal, is rejected, with F greater than F crit. in both cases, at the 95% confidence level. F crit. is 4.747225 for both Figures 2 and 3. The calculated F for Figure 2 is 47.51264. And for Figure 3 is 4.953074.

Much like the crash rate during surface conditions of snow/slush or ice, Connecticut average snowfall (the midpoint of the range of snowfall measured by CTDOT at 26 locations) for winter seasons 2000/2001 through 2012/2013 demonstrates large year-to-year variability (Figure 4). A linear trend line that is overlaid onto Figure 4 shows that even though the average snowfall amount varies significantly from year to year, the long-term trend has been rather flat. The average annual snowfall for six of the winter seasons when deicing was used (2000/2001-2005/2006) is 51 inches, and for the later seven years of anti-icing (2006/2007-2012/2013) is 42 inches.

Lastly, a plot of the average snowfall amount superimposed on average crashes indicates that a direct relationship exists between average seasonal snowfall and number of vehicle crashes with nonfatal injuries when the surface was snow/slush or ice covered (Figure 5).

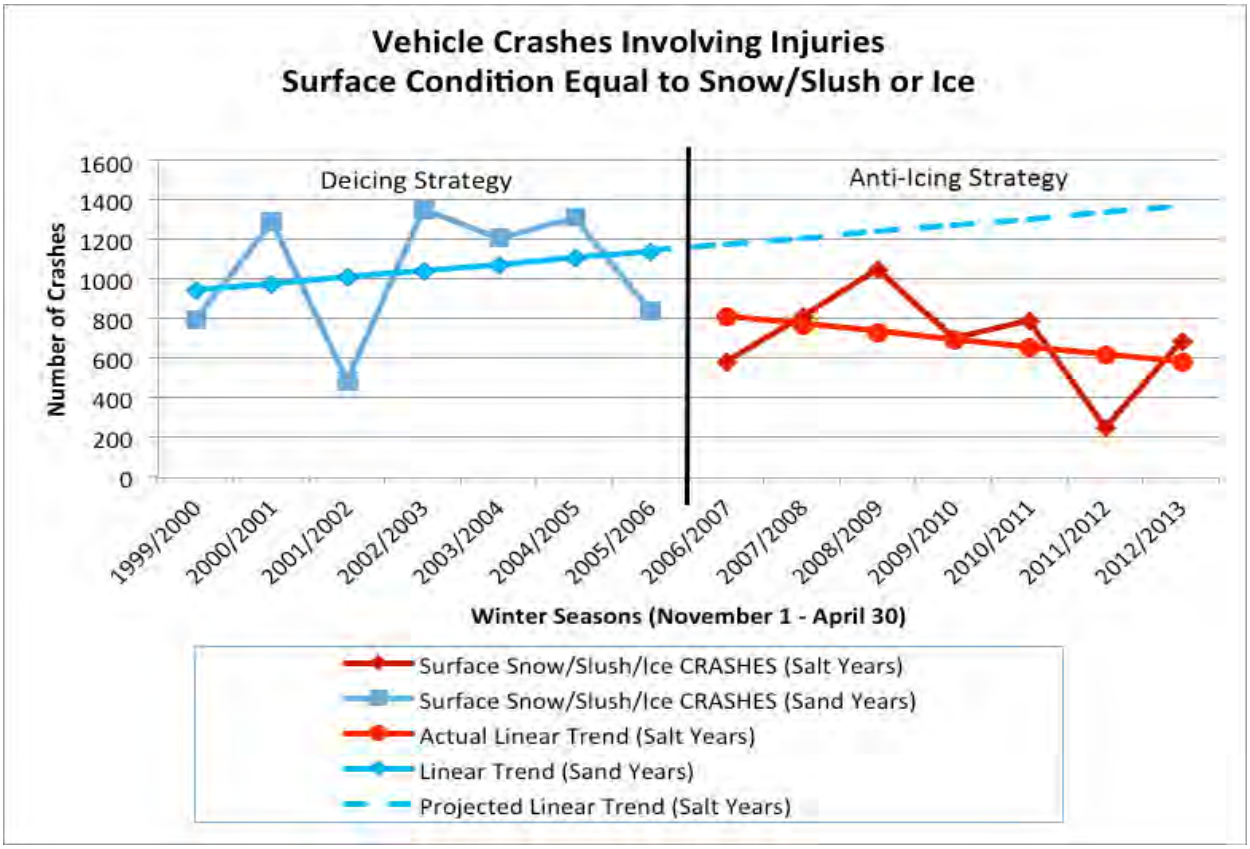

FIGURE 3 Motor vehicle crashes involving nonfatal injuries with pavement surface condition equal to snow/slush or ice.

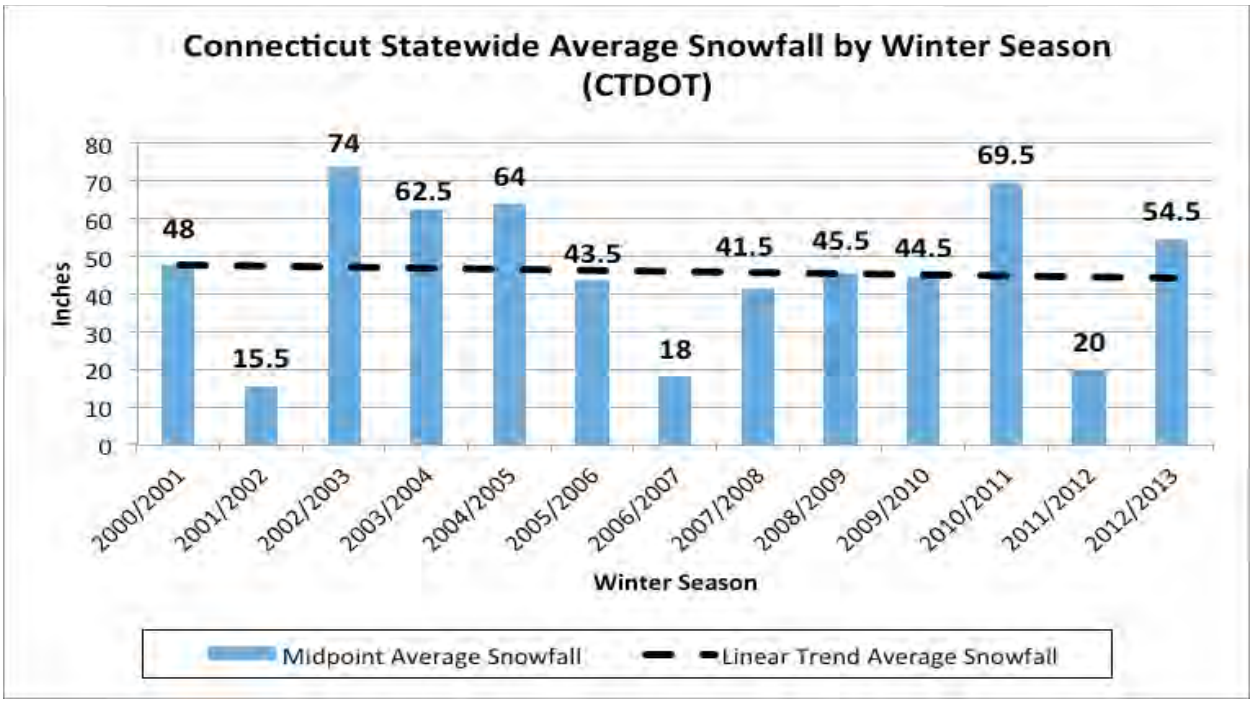

FIGURE 4 Connecticut statewide average seasonal snowfall (data from reference (*2*)).

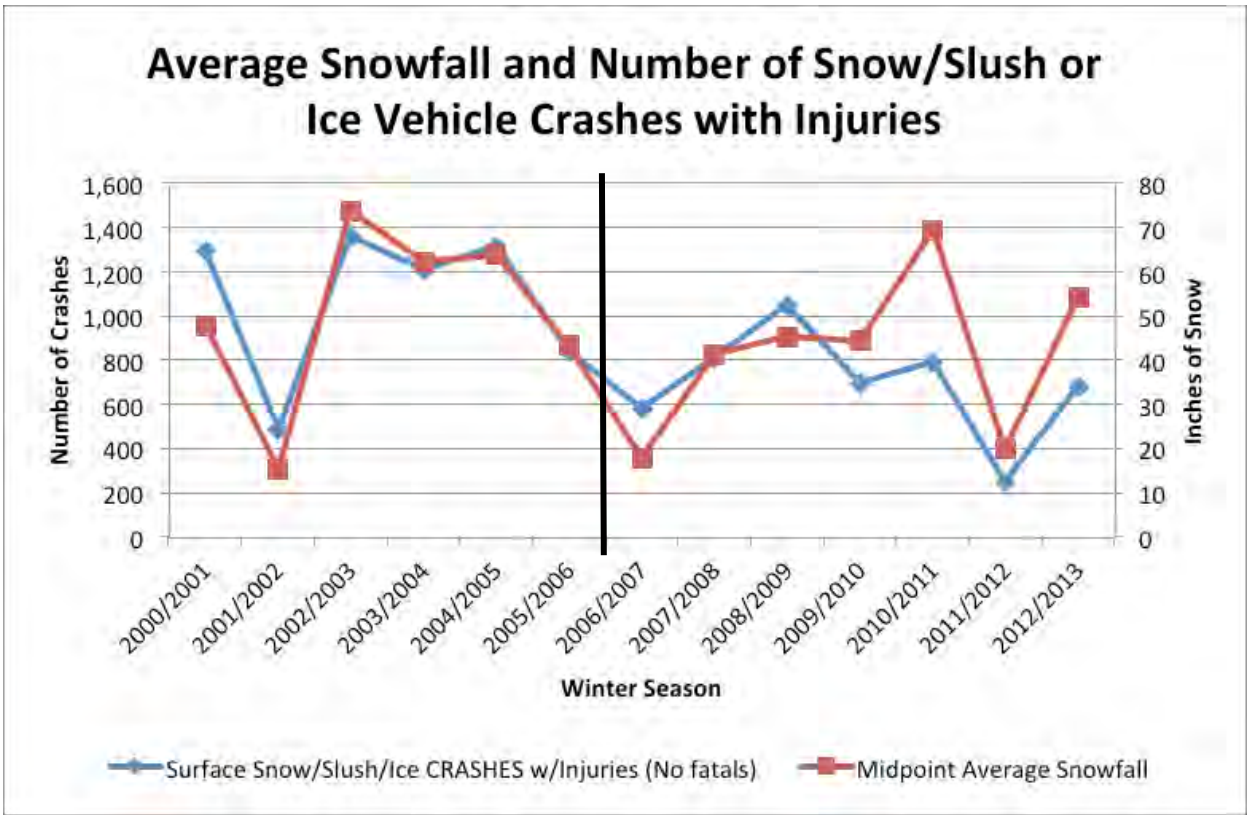

FIGURE 5 Average snowfall and surface snow/slush or ice motor vehicle crashes with nonfatal injuries.

DISCUSSION OF RESULTS

The causes of motor vehicle crashes are many and diverse. A graphical representation of crashes involving nonfatal injuries shows that fewer crashes occurred, particularly in the most recent anti-icing winter seasons compared to the deicing years prior to 2006/2007. Yet, it would be irresponsible to conclude that anti-icing alone accounted for the reduction in vehicle crashes.

All Crashes Involving Nonfatal Injuries

Figure 1, which is a plot of all motor vehicle crashes involving injuries (no fatalities) on Connecticut state-maintained roadways (247,988 injury crashes) that occurred over 14 years from 2000 through 2013, shows that there was a steady decline in annual vehicle crashes nearly every year. This corroborates information cited above at the national level (*7*). Much of the decline in total year-round crashes with injuries is likely the result of improved vehicle safety technology (e.g., anti-lock brakes, air bag restraints, tire tread design, stability control, traction control, all-wheel drive), and possibly as well, increased seat belt usage, law enforcement actions, driver education and safety awareness, and an increase over time of the number of vehicles on the road equipped with state-of-the-art safety technology.

Winter Season Crashes Involving Nonfatal Injuries

Figure 2 shows a significant decline in winter season crashes over time, but with a notable step downward after implementation of anti-icing strategies. Shown in Figure 2, the deicing strategy trend line when projected forward is nearly parallel to the actual trend line for the anti-icing strategy years. However, the actual trend for the anti-icing strategy years is approximately 500 crashes lower than the projected trend. It can be inferred from the trend of the 117,890 vehicle crashes with nonfatal injuries (on state roads only) plotted in Figure 2 that the anti-icing strategy implemented at CTDOT may be responsible for an additional decline in the number of winter weather crashes beginning in the winter season of 2006/2007.

Winter Season Crashes Involving Nonfatal Injuries when Pavement Surface is Snow/slush or Ice Covered

Much of the year-to-year variability in vehicle crashes seen in Figure 3 is related to the number of winter weather events. For example, the low number of crashes during 2001/2002 and 2011/2012 is directly related to the lower number of winter weather events that occurred during those two seasons in Connecticut and the resultant lower total snowfall. It can also be seen in Figure 3 that the trend for motor vehicle crashes with nonfatal injuries under surface conditions of snow/slush or ice is downward since the implementation of an anti-icing strategy. During the deicing years of 1999/2000-2005/2006, the plot of crashes had trended upward. The average number of winter season crashes with injuries in Connecticut for the seven years after anti-icing was implemented is 33.5 percent lower than for the seven prior years when sand and salt were used.

It is noteworthy in Figure 5, where snowfall has been plotted along with crashes, that the later four winter seasons (2008/2009-2012/2013) show a greater variance between snowfall amounts and vehicle crashes, with fewer crashes relative to snowfall amount than for the earlier years. It must be noted that freezing rain events are not included in the weather data plotted in Figures 4 and 5. Admittedly, without this additional information, the relationship of frozen precipitation to

crashes is not completely defined in this analysis. However, due to CTDOT diligence it is a very rare occasion when Connecticut roads are ice covered as a result of freezing rain.

Summary Comparison of Deicing Years and Anti-icing Years

Summary information on the average reduction in crashes extracted from Figures 2 and 3 is presented in Table 1. As previously indicated, these values are based on nonfatal injury-only crashes. There was a 19.2 percent reduction between the average number of winter weather crashes during the deicing and the anti-icing periods for all nonfatal injury crashes plotted in Figure 2, but an even greater reduction of 33.5 percent for the crashes when the surface road condition is listed as snow/slush or ice covered (from Figure 3). Thus, the reduction in surface snow/slush or ice crashes is significantly greater than the general winter season motor vehicle crash reductions that occurred between these two time periods.

TABLE 1 Difference in Average Number of Motor Vehicle Crashes with Nonfatal Injuries on Connecticut State-maintained Roadways for Deicing and Anti-icing Time Periods

Winter Season Months *(November through April)*	**A** Deicing Years *(1999/2000 through 2005/2006)*	**B** Anti-icing Years *(2006/2007 through 2012/2013)*	**A-B**	**(A-B)/A**
	Average number of crashes per winter season over 7 seasons *(Sand and Salt years)*	Average number of crashes per winter season over 7 seasons *(Salt only years)*	Change in average number of crashes between deicing and anti-icing years	Percent change in average number of crashes
All crashes with nonfatal injuries	9,314	7,527	1,787	-19.2%
Crashes with nonfatal injuries when road surface contained snow/slush or ice	1,046	696	350	-33.5%

CONCLUSION

A decline in total vehicle crashes with injuries on Connecticut state-maintained roads over a 14 calendar-year period (1999-2013) mirrors what is found elsewhere in the U.S., and is likely the result of improved vehicle safety technology (e.g., anti-lock brakes, air bag restraints, tire tread design, stability control, traction control, all-wheel drive), as well as an increase over time of the number of vehicles on the road with improved safety technology. Other factors contributing to a

decline may be increased seat belt usage, better law enforcement, driver education and improved safety awareness. When Connecticut winter season crashes with nonfatal injuries are analyzed, using a switch to an anti-icing policy with all salt as a dividing point, there is a notable difference between the seven years of deicing with the sand-salt mix and the seven years of the salt-only applications. For winter season crashes with injuries occurring on snow/slush or ice-covered roads, the salt-only period (2006/2007-2012/2013) shows a distinct decrease in the trends for injury crashes as compared to the trends during the previous seven years of the sand-salt mix (1999/2000-2005/2006). While it is not possible to conclude that the switchover to all salt and the implementation of the latest technology in winter maintenance by CTDOT were solely responsible for the change in the data trends, it is difficult to ignore the obvious significant trends in the nonfatal injury crashes occurring on snow/slush or ice-covered roadways. The reduction in surface snow/slush or ice crashes with injuries of 33.5 percent was significantly greater than just the overall crashes with injuries reduction of 19.2 percent that occurred between these two time periods.

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