LONG-TERM TRENDS IN SNOWFALL-RELATED CRASH RISKS

J. Andrey, D. Hambly
Geography and Environmental Management, University of Waterloo
jandrey@uwaterloo.ca
djhambly@uwaterloo.ca

B. Mills
Adaptation and Impacts Research Directorate, Environment Canada
Brian.mills@ec.gc.ca

ABSTRACT

This study explores whether automobile travel during winter weather has become more or less risky over the past two decades. The analysis is based on the integration of two government databases and a matched-pair framework as a basis for estimating casualty collision risks in Canadian cities during snowfall and other winter weather. Results indicate that the relative risk of a casualty collision during these conditions has not changed significantly over time, although there is some indication that the difference in crash rates between dry/clear conditions and heavier snowfalls may be increasing. Thus, winter precipitation remains a serious safety issue, despite system-wide reductions in casualty rates. These findings are in contrast to rainfall-related risks, where both relative and absolute rates have been declining.

KEYWORDS

SAFETY / TREND / SNOWFALL / RELATIVE RISK / URBAN / CANADA

1. INTRODUCTION

In March 2008, the United Nations General Assembly adopted a resolution (62.244) aimed at easing the global road safety crisis—a crisis that claims the lives of approximately 1.2 million people each year and has intensified over the past two decades as motorization has spread from a largely western phenomena to a global reality. The resolution reminds us that road safety outcomes are the result of two competing forces—the quantity and quality of mobility on the one hand and safety interventions on the other—and it reinforces the need to examine trends as a complement to evaluative studies of the effectiveness of specific engineering, educational or legislative initiatives.

This paper explores the road safety trend associated with travel during winter weather. More specifically, it addresses the question: Is automobile travel in Canadian cities during winter precipitation becoming more or less risky over time? The intention is to create an awareness of broad-scale changes in weather-related risks and to begin a dialogue on how collision incidence and/or severity during inclement weather might be reduced.

A recently published paper by Andrey [1] provides a contrasting depiction of rain- versus snow-related trends in driving risks. Analysis of road casualty data for 10 Canadian cities for the period 1984-2002, shows that driving in the rain has become less risky over time. More specifically, the number of casualty collisions per million vehicle kilometers across all driving circumstances declined from 10.4 in 1984 to 5.1 in 2002 at the same time as the relative risk of casualty during rainfall dropped an average 0.0174 per year from approximately 1.8 in 1984 to 1.5 in 2002. Together these two trends translate into a reduction of nearly 60 percent in the casualty rate during rainfall.

By contrast, the relative risk for snowfall events was found to be unchanged, suggesting that serious collisions during snowfall have been decreasing at approximately the same rate as serious collision rates overall. The current paper explores the snowfall trend in more details—first by expanding the data set used in the analysis to go beyond snowfall events to also include time periods with mixed rain and snow, as well as freezing rain; and second by estimating changes in relative risk for different winter weather conditions.

2. LITERATURE REVIEW

Numerous empirical investigations provide insight into the effects of snowfall and other inclement winter weather on road safety. Two main types of studies appear in the literature. One approach has been to compare safety outcomes during inclement weather relative to normal seasonal conditions in order to estimate relative risk. These studies are based on matched time periods (e.g., six-hour periods or days), thus providing some control over confounding variables. Results consistently show elevated risk levels during snowfall—from 50 percent to several hundred percent, depending on weather severity and other contextual factors [2,3]. A second approach has been to model crash occurrence as a function of traffic, weather and other potential explanatory variables [4-7]. These studies also demonstrate that snowfall is associated with increased crash and casualty risk. The link between snowfall and fatalities, however, is unclear, possibly because of decreased driving speeds, but also because the relatively infrequent nature of fatalities makes it difficult to discern effects.

Increased crash involvements occur despite adjustments at the individual level and interventions at the societal level. In terms of individuals, responses include trip cancellations, travel mode changes, speed reductions and other behaviours that demonstrate increased attentiveness. Related empirical investigations have consistently shown that driver adaptations are in the direction of safety, but are fairly minor except during extreme weather and/or for specific driving situations (e.g., freezing rain) or driver groups (e.g., older drivers). For example, evidence suggests that few automobile trips are cancelled, except for discretionary trips, and during extreme events [8-12], notwithstanding observed short-term variations in traffic volumes that mostly reflect adjustments in travel speeds and associated reductions in highway capacity [13,14]. Similarly, driver compensation in the form of reduced speeds and increased vehicle headways are typically insufficient to provide safe stopping distances, especially under high-volume traffic [14,15].

At the societal level, while a variety of programs exist (e.g., road closures, variable speed limits, snow tire policies), the dominant response is winter road maintenance. Maintenance activities are intended to improve surface friction and/or achieve bare pavement within specified time periods through proactive treatment (e.g., anti-icing) or storm cleanup (e.g., plowing and deicing). An enormous amount of work has gone into modeling road surface conditions as a function of weather and treatment regimes, and new technologies and materials continue to be tested [16].

Evidence on the safety implications of winter maintenance, is comparatively sparse, but is mostly positive, as expected. Nevertheless, results are variable. For example, a recent study on sections of two Canadian highways showed that anti-icing, pre-wetting and sanding operations improved safety, but the safety effect of conventional plowing and dry salt application could not be confirmed [17]. By contrast, the Marquette Report [18], which examined data from the early 1990s along an extensive network of highways in the northern U.S., argued that injury collisions were nine times higher before salt treatment than after, and accident costs were reduced by 88 percent as a result of treatment.

Still, despite the many adjustments by society, risk levels continue to be elevated during snowstorms and other winter weather. The current investigation explores long-term trends in relative risk during these conditions.

3. STUDY CONTEXT AND METHODS

Similar to other highly motorized nations, Canada has made significant progress in road safety over the past three decades. The year 1973 marked a turning point whereby road fatalities stopped increasing year-over-year, and instead began a steady decline as changes in both safety strategies and driving culture began to occur. In that year, 6,706 people died from road crashes. By 2007, the number of road fatalities had been reduced to 2,754 [19] despite large increases in population and personal mobility. Injury rates have also declined substantially over this time period.

In terms of travel, Canada is one of the most auto-reliant countries in the world. Despite its immense size, however, Canada is essentially an urban nation; in 2006, more than two-thirds of Canadians lived in the 33 largest urban areas [20]. Not surprisingly then, 60 percent of road casualties also occur in cities.

The current study is based on data for the eight of these urban areas (Table 1) for which long-term casualty data are consistently available through Transport Canada, the agency that is responsible for Canada's national collision database. These urban areas include the country's two most populous cities (Toronto and Montreal) as well as the nation's capital (Ottawa) and several mid-sized cities. It should be pointed out that 10 cities are listed in Table 1, but Toronto and Brampton are adjacent municipalities for which data are drawn from the same principal weather station, and they are part of the same census metropolitan area. The same is true for Ottawa and Gatineau (National Capital Region).

The eight study locations are located in the eastern half of Canada, six in the Great Lakes-Saint Lawrence climatic region and two in the Atlantic region (Hare and Thomas, 1974). All of the study locations receive more rainfall than snowfall, and total precipitation varies from 800 mm in Toronto, which is located in the heart of southern Ontario, to nearly 1500 mm in Halifax, which is situated on the east coast of the country. In terms of snowfall, Toronto experiences the least snowfall with an average of only 47 snow days and 115 cm of snowfall annually; this stands in contrast to most other regions of eastern Canada where the number of snow days is typically between 60 and 80 and annual accumulations exceed 200 cm.

Table 1 – Characteristics of Study Areas

	Population, 2001 (city)	# of reported casualty collisions, 1984-2002	Annual # of days snow	Annual snowfall (cm)	Annual days with max temp ≤ 0 °C	% time snow	% time other frozen precip
London	336,539	1,016	66	202.4	61.3	9.8	0.1
Sudbury	155,219	1,110	78	274.4	103.9	10.6	0.2
Brampton	325,428	537	47	115.4	57.2	5.8	0.2
Toronto	2,481,494	6,127					
Ottawa	774,072	2,980	66	235.7	81.3	7.3	0.3
Gatineau	102,898	883					
Montreal	1,039,534	4,621	60	217.5	77.4	7.2	0.3
Chicoutimi-Jonquiere	114,850	632	75	303.3	111.0	14.6	0.2
Moncton	61,046	490	64	349.9	74.2	8.3	0.4
Halifax	185,033	657	60	230.5	57.1	5.6	0.4

The analysis is based on the integration of two federal government databases: hourly and six-hourly weather records from Environment Canada and casualty-collision reports from Transport Canada's national collision database (TRAID). Weather observations were taken at a principal weather station, typically an airport, in close proximity to each city. Collision data describe the circumstances of all reported traffic casualties (i.e., fatalities and injured persons).

A matched-pair design is adopted for the study. More specifically, six-hour time periods with winter precipitation, as defined by meteorological records, are paired with six-hour control time periods where inclement weather was absent. Six hours is the finest temporal resolution for which snowfall accumulation data were recorded. Events and controls are defined just one week apart and thus match in terms of season, day of the week and time of day. For example, a snowy Tuesday morning in January is matched with a Tuesday morning just one week earlier or later when the weather was clear and the roads were not icy. If a match does not exist, the precipitation event is not included in the risk estimates.

For the current study, a winter precipitation event is defined as any six-hour period with measurable (≥ .4 mm liquid precipitation equivalent) snowfall, mixed rain and snow, or freezing rain, where precipitation was observed on at least three top-of-the-hour observations, and weather was reported for at least 50 percent of the crash reports. The control periods are characterized by no more than trace precipitation, good visibility, and an absence of both weather and icy road conditions as recorded on the crash reports. These criteria are the same as those used in Andrey [1] and for "scenario one" in Andrey et al. [2].

4. RESULTS

As summarized in Table 2, the pairing exercise produced 6,205 six-hour, event-control pairs (4,308 during snowfall, 693 during rain mixed with snow, and 1,204 during freezing rain events) during which time 19,053 casualty collisions were reported (12,403 during the event periods and 6,650 during the matched control periods). A simple ratio between the latter two numbers (1.865) provides a first insight into the relative risk of injury during winter precipitation relative to normal, seasonal conditions. A risk ratio can be interpreted as percent increase above baseline; a risk ratio of 1.865 indicates that, on average, casualty risk increases by nearly 90 percent during winter precipitation periods.

The relative increase in risk varies by weather condition. As found in previous studies, lighter snowfall is associated with a smaller increase in risk than heavier snowfall. During six-hour events when measurable precipitation occurs but snowfall accumulation is less than 1 cm, the relative risk is estimated to 1.476, i.e., approximately 50 percent higher than during good winter driving conditions. For accumulations of between 1 and 2 cm and for periods with more than 2 cm of snowfall accumulation, the values are 1.888 and 2.189, respectively. For those events where rain preceded or followed snow, the point estimate is 1.716; and for freezing rain conditions it is 1.935. All of these are significantly above 1.00

Table 2 – Risk Estimates and Trends

	Total 6-hour events	Event-control pairs	Casualty collisions			Risk ratio	Slope of Trend Line
			Events	Controls	Total		
All winter precipitation	12,894	6,205	12,403	6,650	19,053	1.865	-0.0008
Snow (all)	9,183	4,308	8,107	4,324	12,431	1.875	+0.0013
0.39-1.00 cm	3,748	1,709	2,145	1,453	3,598	1.476	-0.0174
1.01-2.00 cm	2,097	953	2,024	1,072	3,096	1.888	+0.0089
> 2.01 cm	3,338	1,646	3,938	1,799	5,737	2.189	+0.0166
Rain with snow	1,262	693	1,603	934	2,537	1.716	+0.0110
Freezing rain	2,449	1,204	2,693	1,392	4,085	1.935	-0.0031

While detailed maintenance records for all 10 cities over the 19 years are not available, it is reasonable to assume that most of the events associated with less than 1 cm of snowfall were unlikely candidates for treatment given existing maintenance guidelines. By contrast, those associated with 2 cm or more of snowfall and also those events with freezing rain most likely coincided with maintenance activity, with treatments varying according to specific weather conditions and road priorities. For the other two event categories (snowfall accumulation between 1 and 2 cm; and mixed rain and snow which often occurs in the transition seasons) it is difficult to make any generalized statement about treatment. Overall, however, one can see that, regardless of the nature of the precipitation event and the likelihood of treatment, casualty rates are highly elevated during winter precipitation events, suggesting that driver adaptations are insufficient for road conditions.

Figure 1 summarizes the overall trend in relative risk of casualty collision during winter precipitation from 1984 to 2002. As shown here, there has been virtually no change in the relative risk of casualty collision during inclement winter weather over the study period. Point estimates for individual years vary (95% confidence intervals shown) possibly due to differences in the weather composite of the different years, but there is no systematic change over time, as indicated by the trend line slope, which is virtually zero (Table 2).

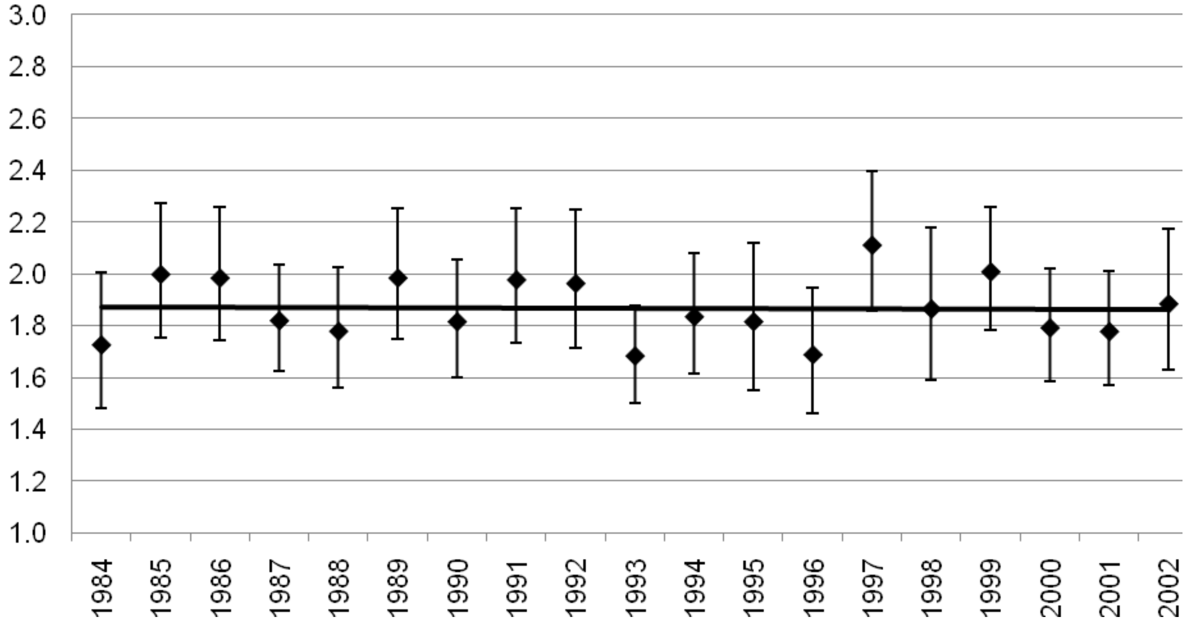

Figure 1 - Trend in risk of casualty collision during winter weather, 1984 to 2002

Figure 2 and Table 2 summarize the risk patterns over time for the five event subsets. However, it is important to note that none of the slopes are statistically significant due to a combination of modest sample sizes and a high degree of variability in relative risk from event to event. Thus, at this point, it must be concluded that there is no evidence of a significant trend in relative risk during winter precipitation events of various types.

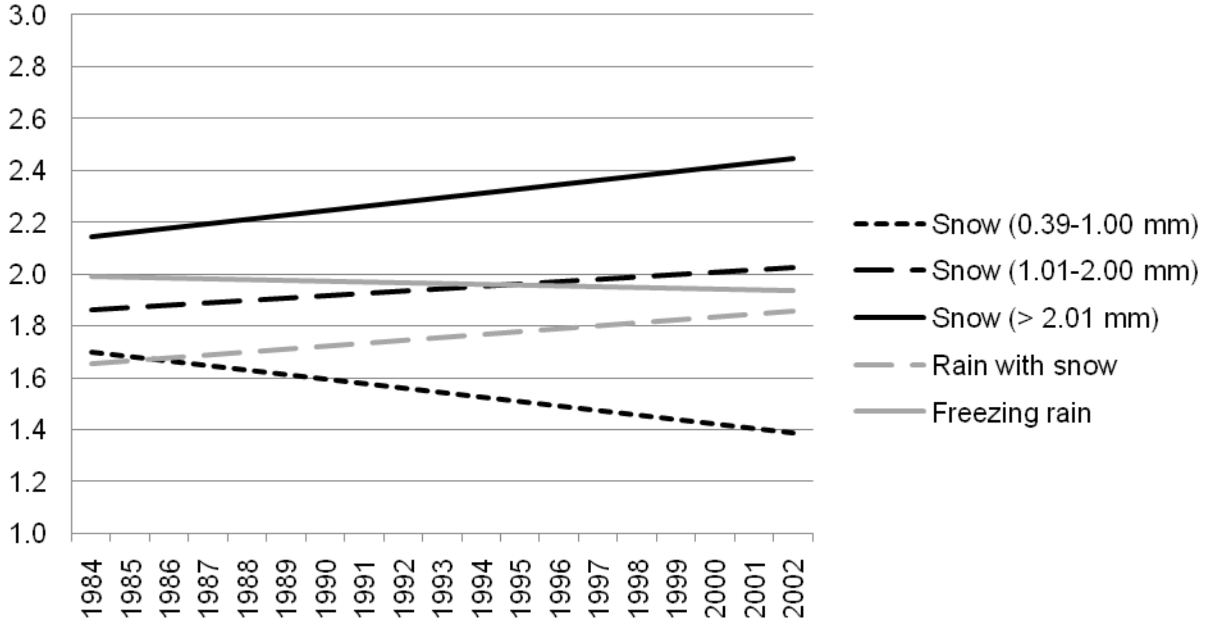

Figure 2 - Trends in risk of casualty collision by weather condition, 1984 to 2002

Still, the graphs illustrate interesting patterns that warrant further investigation—a negative slope for events with lighter snowfalls (< 1 cm), virtually no slope for freezing rain events, and positive slopes for heavier snowfalls and events characterized by mixed rain and snow. The latter is of particular concern; if future studies were to confirm this upward trend, this would be an indication that society is being becoming less well adapted to inclement weather. Although it is purely speculative at this point, increased driving speeds perhaps due to a false sense of comfort or a faster pace of life would be the type of mal-adaptation that could lead to such trends. Since winter road maintenance is essentially about road friction rather than about safety *per se*, elevated risk levels during winter weather reminds us that interventions that address driving itself are a necessary complement to engineering and other technical solutions.

5. SUMMARY AND CONCLUSIONS

Road safety research typically focuses on drivers, vehicles, and roads. Indeed, Evans [21] in his book entitled *Traffic Safety*, states that “Weather is not part of the main structure because there is not much that can be done to change it, and, unlike the other factors, it remains relatively constant over the decades.” (p 333). As the road maintenance community knows, much is being done to ameliorate driving risk during inclement weather; and climate variability and change are factors to be considered in planning for the future.

In fact, an emphasis on situational risk factors in road safety provides a complementary approach for identifying priority areas and assessing safety progress. Given the difficulty of ascertaining the contribution of individual countermeasures to changes in safety outcomes, and the importance of what Page [22] refers to as “exogenous to safety performance” factors, one approach for targeting resources is at problematic situations. Situational risks are already embedded in the design of graduated and conditional licensing programs [23] They also account for the large-scale investments of nighttime lighting in urban areas [c.f. 24,25].

With respect to weather, safety professionals have known for some time that crash rates are elevated during precipitation, and there is growing appreciation that specific combinations of weather with other circumstances are particularly problematic, e.g., heavy traffic or horizontal curves in conjunction with precipitation [24]. While safety professionals cannot “change the weather”, weather and other situational factors that contribute to total risk must be taken more seriously in setting and working toward national safety goals. If safety interventions are deemed effective in some situations but not others, this provides an opportunity to revise or expand safety programs. As well, if changes in exogenous variables are associated with heightened risk during a particular situation, then this also provides an opportunity to address concerns in ways that target resources appropriately.

With respect to the specific objective of the study, the main conclusion is that no discernible trends are observed in relative risk during winter precipitation, suggesting that snow-related casualty rates decreased in ways consistent with the aggregate trend. It would be prudent to investigate weather-related crash trends further and to document the effects of related policies (e.g., the Province of Quebec has mandated snow tires from November 15th to April 15th, effective autumn 2008). It would also be prudent to explore the extent to which driving speeds during snowy/icy conditions have changed over time, as a way of improving our understanding as to why rainfall and snowfall produce different temporal trends in the relative risk of casualty collision.

Lastly, it is worth noting that snowfall-related casualty rates remain elevated. The point estimate from 1984 to 2002 is approximately 1.9. Thus, winter weather represents a serious challenge to road authorities and policy makers alike, as this degree of increase is similar to or higher than other risk factors that are taken very seriously, for example low levels of alcohol impairment or moderate levels of speeding on urban roads [21]

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