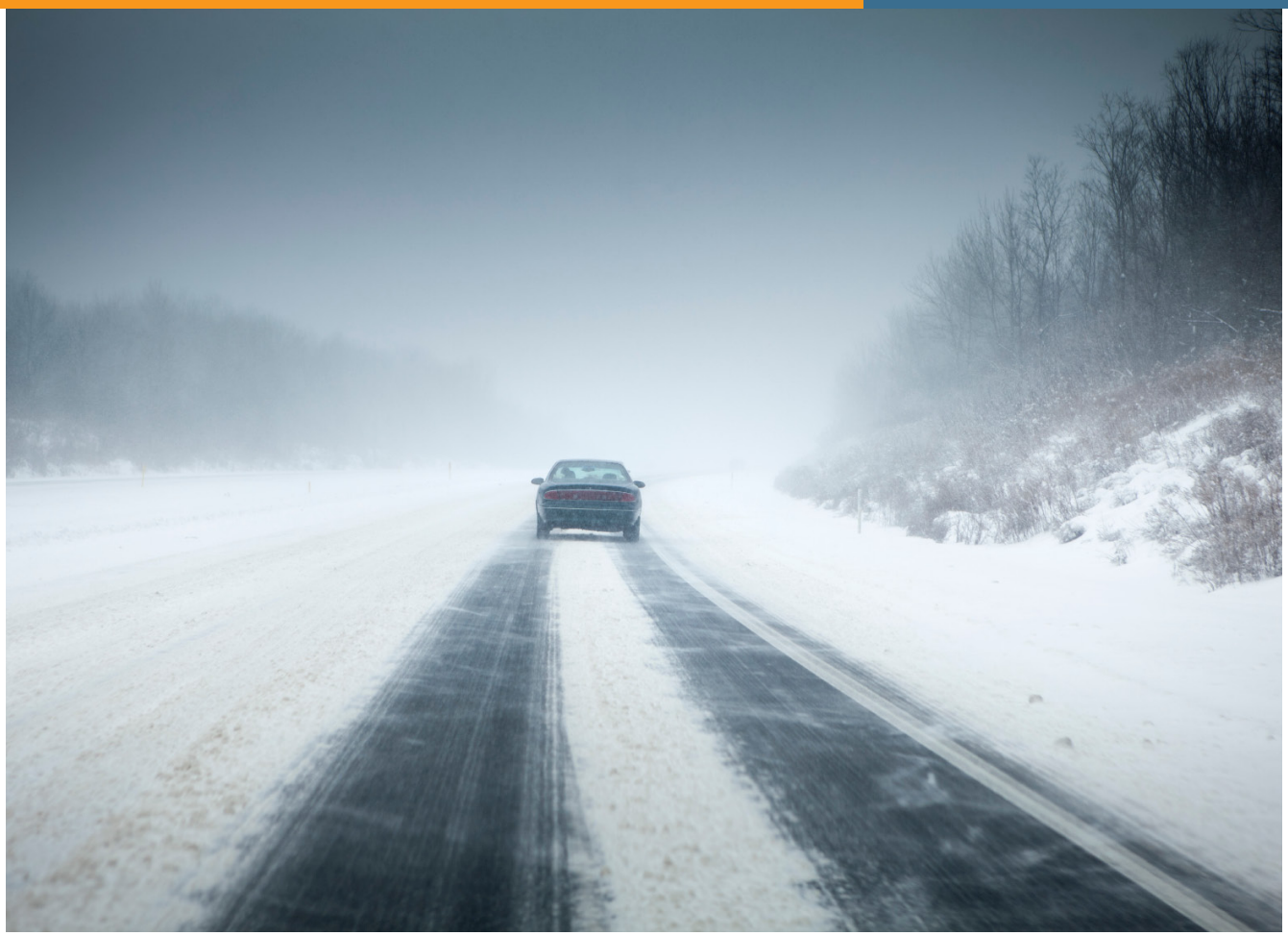
TRAFFIC INJURY RESEARCH FOUNDATION



WINTER TIRES: A REVIEW OF RESEARCH ON EFFECTIVENESS AND USE

TIRF

The knowledge source for safe driving

The Traffic Injury Research Foundation

The mission of the Traffic Injury Research Foundation (TIRF) is to reduce traffic-related deaths and injuries. TIRF is an independent, charitable road safety institute. Since its inception in 1964, TIRF has become internationally recognized for its accomplishments in identifying the causes of road crashes and developing program and policies to address them effectively.

Traffic Injury Research Foundation
171 Nepean St. Suite 200
Ottawa, ON K2P 0B4
Ph: (613)238-5235
Fax: (613)238-5292
Email: tirf@tirf.ca
www.tirf.ca

February 2012
Traffic Injury Research Foundation

ISBN: 978-1-926857-26-8

WINTER TIRES:

A REVIEW OF RESEARCH ON EFFECTIVENESS AND USE

Steve W. Brown / Ward G.M. Vanlaar / Robyn D. Robertson

Traffic Injury Research Foundation

TABLE OF CONTENTS

EXECUTIVE SUMMARY

A significant number of people are killed and injured in road crashes in Canada each year. Not surprisingly, this is a leading cause for public concern and efforts are needed to mitigate crashes. One mitigation strategy that is garnering more attention is the use of winter tires to reduce winter crashes and improve driver safety in a wide range of winter road conditions. Available information about this topic suggests that winter tires improve acceleration, handling and braking of vehicles in winter conditions (i.e., wet, slushy, snowy, icy and dry cold surfaces). However, generally speaking, many drivers in Canada do not use winter tires, for a variety of reasons. It is not clear whether or not increased use of winter tires has had an impact on the number of crashes, injuries and fatalities.

The Traffic Injury Research Foundation (TIRF) was contracted by the Winter Driving Safety Coalition comprised of the Canadian Automobile Association South Central Office, Ontario Safety League, Rubber Association of Canada, Ontario Hospital Association and Canadian Tire to review the literature on winter tires and safe winter driving. The objective of this work was to compile and review available information and develop a current state of knowledge regarding the efficacy of winter tires and their potential effects on traffic safety, within the broader context of safe winter driving strategies. This was pursued using a thorough review and analysis of existing domestic and international research and an environmental scan for relevant winter tire information.

The review also provided insights into the strengths and weaknesses of the existing body of research about winter tires. Several weaknesses were identified, including:

- Outdated nature of research materials;
- Limited data comparability and compatibility;
- Gaps in data collection;
- Inattention to the winter tire issue; and,
- Proprietary nature of research.

An overview of winter tire initiatives at three levels in Canada was also provided, including the national and provincial level as well as industry level initiatives.

Based on the available information from experimental studies and demonstration projects it appears that in winter driving conditions, winter tires outperform other types of tires, notably all-season tires and summer tires. Also, based on available public opinion research about winter tire usage, it appears the public does not fully appreciate the benefits of winter tires, suggesting education may be beneficial. However, despite the apparent advantages of using winter tires, the research available about this topic is outdated and fairly

limited. More precisely, there is an insufficient body of literature, especially in terms of epidemiological collision studies to validate the limited experimental findings in that it is not clear how these experimental findings carry over into the real world. More precisely, the question whether this apparent advantage of superior performance of winter tires in winter conditions translates into fewer collisions, injuries and fatalities remains largely unanswered. The issue is compounded by the fast and continuous improvements to winter tire technology in recent years. While more studies focusing on the effectiveness of modern winter tires may become available, findings can still be considered limited and more research is needed to better understand how this new technology can help improve traffic safety. As it stands today, more research would be beneficial to further inform sound decision-making.

It is also important to recognize that proper use of winter tires is only one aspect of safe winter driving. There are many other aspects that are important including overall vehicle preparedness and defensive driving techniques. While such aspects were beyond the scope of this report, the findings described in this report are not meant to, and therefore must not be used to limit the discussion of safe winter driving to the use of winter tires only.

Based on the findings from this study, recommendations regarding follow-up research and public education were formulated.

INTRODUCTION

A significant number of people are killed and injured in road crashes in Canada each year. Not surprisingly, this is a leading cause for public concern and efforts are needed to mitigate crashes. One mitigation strategy that is garnering more attention is the use of winter tires to reduce winter crashes and improve driver safety in a wide range of winter road conditions. Studies suggest that winter tires improve acceleration, handling and braking of vehicles in winter conditions (i.e., wet, slushy, snowy, icy and dry cold surfaces). However, in an online poll conducted among Ontario drivers by Ipsos Reid for Canadian Tire, only 47% of respondents claimed that they used winter tires (Ipsos Reid 2010). Despite the apparent advantages, there are obstacles to increased winter tire use. They are perceived to cost more than other types of tires. Some consumers believe that winter tires have a higher rolling resistance coefficient and, as a consequence, offer less fuel economy. And there are those who do not intend to use winter tires for a variety of reasons including a lack of storage room for another set of tires, a belief that their regular tires are satisfactory, and that their roads are well-maintained or their region does not receive much snow (Ipsos Reid 2010).

Estimates of the extent of crashes resulting from weather-related collisions generally or winter conditions specifically provide some insight into the magnitude of the problem and its costs. Nationally, using aggregate risk and cost data, it was estimated that weather-related collisions in Canada cost $1.1 billion per year (Andrey and Mills 2003), and among these collisions are those that occur in winter conditions. Provincial measures from the Royal Canadian Mounted Police (RCMP) in British Columbia claim that the fall and winter seasons are when motorists are most inclined to speed and drive too fast for road conditions and that 44% of casualty collisions can be attributed to these factors (British Columbia RCMP 2010). More recently, over a five-year period, Aviva Canada reported a 49% increase in customer auto claims between December and February in comparison to the rest of the year (Aviva Canada 2011). Among overseas studies, the United Kingdom (UK) Department for Transport statistics reported that in 2003, 48% of collisions are caused by skidding during winter conditions, as opposed to 11% during dry conditions and 19% during wet conditions (eTyres 2004).

Among Canadian jurisdictions, Quebec is the only jurisdiction that has mandatory winter tire legislation throughout its borders and in British Columbia, vehicles must be equipped with winter tires or the operator must carry chains to be permitted access on designated roads (principally in mountainous terrain). As of January 2010, several European countries with winters comparable to Canada made winter tires mandatory; these countries include Sweden, Estonia, Finland, Romania, and Slovenia. In Austria, Latvia, Norway and Slovakia, winter tires are required if weather conditions are adverse. Other countries such as

France, Spain and the Czech Republic require winter tires only where a specific road sign indicates the need for such tires (ECC Net 2010).

Generally speaking, there has been a gradual increase in the number of Canadian drivers choosing to use winter tires. A 2002 study showed that an average of 42% of Canadian drivers switched tires in the winter months, ranging from 30% among Prairie drivers to 60% of Quebec drivers (CBC 2006). In Quebec, the percentage of drivers installing winter tires on their primary vehicles increased from 66% in 1995 to 90% in 2005 (Transports Québec 2011b).

Table 1 shows the percentage of drivers using winter tires by jurisdiction according to the results of three separate studies. The three studies are a telephone survey commissioned by RBC Insurance in 2008, a 2011 Rubber Association of Canada (RAC) study based on shipment data through 2010, and an online survey commissioned by Canadian Tire in 2011.

The 2011 RAC study suggests that 51% of Canadians use winter tires ranging from a low of 18% in Manitoba to a high of 98% in Quebec; in Ontario, winter tire usage was 39% (Rubber Association of Canada 2012). The most recent Canadian data from an online poll conducted for Canadian Tire shows that 57% of Canadians use winter tires, ranging from 28% in Alberta to 98% in Quebec (North Strategic 2011). Among Ontario respondents, 43% say that they use winter tires. When one subtracts Quebec respondents from this poll, the incidence of winter tire use drops to 43% across Canada. By comparison, in Germany it is reported that 43% of all vehicles are fitted with winter tires each year (eTyres 2004).

Table 1: Percentage of drivers using winter tires by jurisdiction in Canada

<table>
<tr><th>Jurisdiction</th><th>RBC Insurance Telephone Poll 2008</th><th>2011 RAC Data based on Shipments through 2010*</th><th>Canadian Tire Online Survey 2011</th></tr>
<tr><td>BC</td><td>48</td><td>27</td><td>41</td></tr>
<tr><td>AB</td><td>41</td><td>35</td><td>28</td></tr>
<tr><td>SK</td><td>31</td><td>26</td><td rowspan="2">40</td></tr>
<tr><td>MB</td><td>31</td><td>18</td></tr>
<tr><td>ON</td><td>43</td><td>39</td><td>43</td></tr>
<tr><td>QC</td><td>96</td><td>98</td><td>98</td></tr>
<tr><td>NB</td><td rowspan="4">72</td><td rowspan="4">55</td><td rowspan="4">68</td></tr>
<tr><td>NS</td></tr>
<tr><td>PE</td></tr>
<tr><td>NL</td></tr>
<tr><td>YK</td><td>Unknown</td><td>Included with BC</td><td>Unknown</td></tr>
<tr><td>NT</td><td>Unknown</td><td>Included with Alberta</td><td>Unknown</td></tr>
<tr><td>NU</td><td>Unknown</td><td>Unknown</td><td>Unknown</td></tr>
<tr><td>Canada</td><td>Unknown</td><td>51</td><td>57</td></tr>
<tr><td>Canada excluding Quebec</td><td>Unknown</td><td>36</td><td>43</td></tr>
</table>

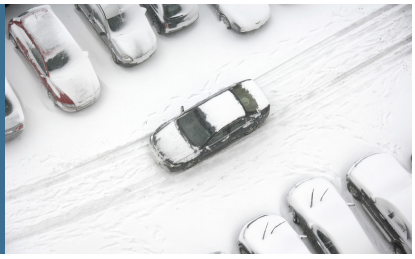
*RAC Winter Tire Usage by Region/Province is derived from tire shipment and vehicle registration data. It does not reflect the impact of the higher use of winter re-treaded tires more common in Eastern Ontario.

Several public perceptions may discourage greater use of winter tires. First, there is the cost of spending money on an extra set of tires and rims. There is also the belief that one's current set of tires is sufficient to cope with winter driving. Some Canadians do not believe that the winters in their jurisdiction are severe enough to warrant the use of winter tires. Vehicle safety features such as Antilock Braking System (ABS) brakes and electronic stability control (ESC) may be considered by some drivers as negating the need for winter tires. And lastly, some people believe that winter tires compromise fuel efficiency.

The Traffic Injury Research Foundation (TIRF) was contracted by the Winter Driving Safety Coalition comprised of the Canadian Automobile Association South Central Office, Ontario Safety League, Rubber Association of Canada, Ontario Hospital Association and Canadian Tire to review the literature on winter tires and safe winter driving. The objective of this work is to compile and review available information and develop a current state of knowledge regarding the efficacy of winter tires and their potential effects on traffic safety, within the broader context of safe winter driving strategies. This was pursued using a thorough review and analysis of existing domestic and international research and an environmental scan for relevant winter tire information.

This report contains a description of the methodology used to conduct a review of the literature on winter tire use as well as a brief survey among members of the Canadian Council of Motor Transport Administrators (CCMTA). Sources that were analyzed in the literature review are categorized by the nature of the study (i.e., experimental studies, epidemiological collision studies, and reviews already conducted on the available literature on winter tire use). Relevant findings from other sources such as public opinion polls and websites, bulletins, newsletters, newspaper and magazine articles have also been reviewed. This report further describes the results from the literature review and limitations of the available research. Conclusions and recommendations are formulated at the end of this report.

METHOD



A literature search was conducted within the libraries of TIRF, the Transportation Research Information Service (TRIS), the University of Michigan Transportation Research Institute (UMTRI) and the Canadian Association of Road Safety Professionals (CARSP) for any reports, articles, news releases or bulletins dealing with winter driving and tires. In addition, a web search was performed in an effort to obtain the most recent materials available in the broader traffic safety field. The period covered by the literature review was from 1985 to 2011, although some older materials were located and analyzed. Google Scholar was also searched. Keywords used were "winter tires", "all-season tires", "snow tires", "effectiveness", "performance", "collision", and "all-weather tires".

The origins of the research and literature reviewed in this report can be categorized by the type of agency conducting or at least commissioning the research. The types of agencies and the number of reports and studies from each sector include:

- government departments (5);
- academic or research organizations (19); and,
- industry (tire manufacturers, vehicle manufacturers, insurance companies, and tire retailers) (7).

The goals and motivation of the research conducted on this topic can be related to the type of agency performing the analysis. For example, research on winter tires being performed by a government department may be done to determine the potential need for legislation or measure the effectiveness of existing legislation. Research performed by industry could be performed as a means of improving existing tires or educating the public of the advantages and disadvantages of various types of tires.

Of the thirty-one reports and studies examined, most originated outside of Canada, primarily from Europe. Most Canadian research comes from Quebec (five of seven studies). Of the remaining twenty-four studies, nine were from the United States, six from Sweden, three from Finland, two each from Norway and Lithuania, and one each from Japan and Germany.

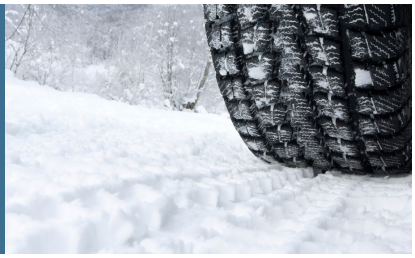
In an effort to augment the results from the literature review, a brief questionnaire was sent by TIRF to a stakeholder group of representatives from two CCMTA committees. Representatives from the Standing Committee of Road Safety Research and Policies and the Standing Committee of Drivers and Vehicles were asked to provide TIRF with information on any initiatives that their respective jurisdictions were involved in that dealt with winter tire use, including data collected, studies performed, legislation under consideration, or any other initiatives that would promote, encourage or offer incentives for the use of winter tires.

Conference calls were also arranged with members of the Winter Driving Safety Coalition during which TIRF provided a status update on the literature review and information received from CCMTA representatives on winter tire use. Members of the Winter Driving Safety Coalition were also asked to provide TIRF with their experiences and to identify any specific materials that had not been captured by the literature review. The calls took place between November 22 and December 12, 2011. Coalition members that were contacted by conference call included Canadian Tire's Government Relations and Tire Business Managers; the Government Relations Manager, the Director of Government and Community Relations and Driver Training, and a Researcher for the Canadian Automobile Association South Central Ontario; the Director of Operations for the Rubber Association of Canada, and the President of the Ontario Safety League.

Other contacts that were interviewed to provide their perspective on winter tire use were the Director of Marketing at Transport Canada, the Vice-President of Accident Support Services International Limited, and the Senior Manager of Public Relations for Aviva Canada.

In addition, coalition members were asked to provide industry contacts whose knowledge and experience would inform TIRF on winter tires. Areas of interest included the efficacy of winter tires, existing epidemiological studies examining collision rates for vehicles equipped and not equipped with winter tires, incentives promoting winter tire use (provided by either tire manufacturers, insurance companies, or governments), and any limitations to the research.

TYPE OF TIRES



The five principal types of tires that were examined in the literature review include:

- summer tires;
- all-season tires;
- all-weather tires;
- winter tires (sometimes referred to as friction tires); and,
- studded tires.

Summer Tires

Also referred to as "performance tires", summer tires are the tires that most manufacturers put on new vehicles before the advent of all-season tires. Summer tires have large tread blocks with high lateral stiffness. The rubber is formulated to enhance performance in warmer weather with little regard given to handling on ice or snow (Edmunds 2009). These tires do not have the mud and snow (M+S) symbol. If summer tires are used in temperatures of -20 degrees Celsius or colder, permanent damage could occur to the tread compound of the tires since they lose their elasticity and become brittle (Continental Corporation 2011).

All-Season Tires

All-season tires are not specifically designed for one specific weather condition. Instead, they are designed to perform optimally in wet and dry conditions, and satisfactorily in other conditions. Since all-season tires are now generally the default tire on many new cars, they need to simultaneously minimize noise levels, maximize tread life, and promote fuel economy by means of a low rolling resistance. All-season tires, in short, are being asked to perform many tasks (Edmunds 2009). Limitations in the design of an all-season tire in winter conditions include a less aggressive tread design that compromises traction, less flexibility in cold weather, and a tendency for the tread to become snow-packed with snow and inhibit traction (www.1010Tires.com; accessed November 21, 2011).

All-Weather Tires

All-weather tires carry the mountain and snowflake logo but their manufacturers also recommend them for summer use. Since they are a relative newcomer to the tire market, there is a lack of certainty among leading tire manufacturers about whether all-weather tires should be categorized as a distinct type of tire. These tires are said to use a hybrid tread that meets winter tire traction requirements on snowy surfaces, yet are made from a unique compound that is more characteristic of conventional all-season tires. In

the fall of 2011, all-weather tires were actively promoted across Canada as a whole, with emphasis on their hybrid nature (Canadian Tire 2011a). These tires were also targeted in Pacific Coast markets such as Vancouver, where icy surfaces and wet weather can be encountered but where roads are relatively free of snow (Automobile Protection Association 2011). In short, all-weather tires can be left on one's vehicle throughout the entire year and, although they have better winter performance than all-season tires, they do not possess the grip levels of a "good ice and snow tire" (Mahler 2009).

Winter Tires

The newer generations of winter tires are designed with a more flexible rubber compound that is less prone to stiffen in colder temperatures and its tread is designed to provide improved traction on wet, slushy, snowy, icy and dry cold surfaces (Rubber Association of Canada 2007a). Tires designed for use in severe snow conditions are recognized by a three peaked mountain snow flake symbol (see Figure 1). This symbol, created by tire manufacturers, is a performance based standard which indicates the winter tire achieves a snow traction index of 110% when using the ASTM F-1805 snow traction test, compared to a known control tire (Standard Reference Test Tire). The symbol is now used around the world to identify dedicated winter tires. Winter tires have a softer tread and will wear out quicker than all-season tires (Fountain Tire 2011). However, according to Bill VandeWater of Bridgestone Tire, a winter tire has better traction at -40 degrees Celsius than an all-season tire does at +4 degrees Celsius (Mahler 2008a).

Figure 1: Three peaked mountain snow flake symbol used for tires designed as winter tires

Within the winter tire group itself, some tires appear to outperform others at various tasks or in differing conditions. A Swedish study examining stopping distances of various winter tires suggested a classification system within the winter tire group where winter tires would be categorized as Nordic winter tires, European winter tires, and South European winter tires (Engström et al. 2009).

Studded Tires

Studded tires were produced in the early 1960s to combat the high number of traffic collisions in northern countries where winter driving conditions were common (e.g., Sweden, Norway). Like winter tires, studded tires have a more resilient compound and aggressive tread than tires used in non-winter months. The gripping ability of studded tires is augmented by the inclusion of studs or pins which are made of metal or ceramic. However, many countries have banned the use of studded tires because of the high level of dust emissions attributed to these tires. As the study of air quality has moved beyond hazardous inhalable particles in the air attributable to vehicle exhaust, more studies have examined the impact studded tires

have on the environment. In Japan, it was reported that dust concentrations in the air decreased after the ban on studded tires (Kupiainen and Tervahattu 2004). Laboratory tests showed that studded tires yield 60-100 times more particle concentrations than non-studded tires on some pavements (Gustafsson et al. 2008).

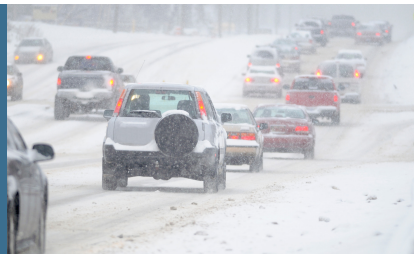
Another drawback of studded tires is the damage that they inflict on pavement. In Canada where laws concerning the use of studded tires are provincially regulated, most provinces restrict use of studded tires to winter months since they can make ruts and dislodge chunks of pavement from the road surface (Corkill 2010). In the early 1990s in Sweden, studded tire pavement displacement amounted to 450,000 tonnes per winter season (Angelov 2003).

Summary of Types of Tires

To summarize the non-studded types of tires commonly used in Canada, a simple rating system of current tire types would be as follows:

- Summer tires: best for summer, fair in spring and fall, poor in winter;
- All-season tires: fair in spring, summer and fall, less satisfactory in colder conditions (+7 degrees Celsius or colder);
- All-weather tires: good in winter but not as good as "winter" tires, fair in spring, summer and fall; and,
- Winter tires: best in winter, fair in spring and fall (but lose tread sooner), poor in summer; (Russell 2011).

LITERATURE REVIEW



A breadth of literature was reviewed from several sources. Some of the studies included in the current literature review have been peer-reviewed while others have not. The literature that was reviewed for this report is summarized using the following categories:

- Experimental studies that compare different tire types in a controlled environment (snowy and icy tracks);
- Epidemiological studies that examine collision rates by type of tires used on the vehicle involved;
- Literature reviews;
- Public opinion polls that explore public attitudes, perceptions and self-reported behaviours, and,
- Websites/bulletins/newsletters/newspaper and magazine articles.

Several reports and journal articles have been produced that provide a comparison of the effectiveness of different types of tires in winter driving conditions (see References). Also reviewed were newspaper and magazine articles, news releases and bulletins that were available online.

Experimental Studies and Demonstrations

In this section, individual experimental studies and demonstration projects that compared different types of tires are described and summarized (the latter – demonstration projects – use a less rigorous evaluation design whereas the former – individual experimental studies – adhere to a stricter scientific evaluation protocol). Additional information for the studies such as performing agency, study location, type of vehicle used, type of road surface, temperature, safety features of vehicles (e.g., ABS), are included in cases where such characteristics were available. Comparisons are made between:

- Studded tires versus winter tires;
- Studded tires versus winter tires versus all-season tires;
- Winter tires versus all-season tires;
- Winter tires versus all-season tires versus summer tires;
- Winter tires versus summer tires;
- Four winter tires versus two winter tires;
- Premium winter tires versus economy winter tires.

Studded tires versus winter tires. As studded tires become less common, or in some jurisdictions, illegal, it is important to note that winter tire technology improves continuously as manufacturers release their newest tire models (Zubeck et al. 2004). In a Lithuanian experimental study conducted by Vilnius Gediminas Technical University, vehicles equipped with non-studded winter tires had superior deceleration

compared to vehicles with studded winter tires by margins of 3.6% on wet surfaces, and 15.6% on wet snowy surfaces (Mitunevicius et al. 2009).

Studded tires versus winter tires versus all-season tires. In 1994 an experimental study was performed by the University of Alaska Fairbanks in partnership with the Alaska Department of Transportation and Public Utilities. Studded tires, winter tires and all-season tires were tested for stopping distance, starting traction, cornering speed and winter hill climbing ability (Lu et al. 1994). Mid-size front wheel drive cars, large rear wheel drive cars, and half-ton rear wheel drive pickup trucks were used on snow-packed, icy, and dry surfaces. Stopping distances were almost equal for all three types of tires on snowy surfaces. On icy surfaces, compared to vehicles equipped with all-season tires, stopping distances were improved by winter tires (8%) and studded tires (8-10%).

In the starting traction tests, vehicles were measured for the time required to reach speeds of 40 km/h. On snow-packed surfaces, winter tires and studded tires each took 10-20% less time to reach this speed than did all-season tires. On icy surfaces, studded tires and winter tires also took less time to accelerate than all-season tires (29% and 13% respectively). However, on dry pavement, both winter tires and all-season tires took 6-9% less time than studded tires to accelerate to 40 km/h.

On both snow-packed and icy surfaces, no significant differences were observed for the three types of tires in terms of maximum cornering speed. Due to vehicle rollover potential, cornering tests were not performed on dry pavement.

In tests of winter hill climbing ability, all three types of tires were able to climb grades of 15-16% on packed snow surfaces. On icy surfaces, studded tires were able to climb grades of 10-12%, an improvement of 1% compared to winter tires and 2% compared to all-season tires.

Winter tires versus all-season tires. In an experimental study conducted by Transports Québec, the effectiveness of winter tires and all-season tires were compared at temperatures of -2 degrees Celsius and -20 degrees Celsius with sub-compact automobiles, minivans, and 4-wheel drive vehicles. Three different driving manoeuvres were executed: braking in a straight line, accelerating in a straight line, and an avoidance manoeuvre. In the braking test, for all vehicle types, winter tires offered superior braking performance. For sub-compact automobiles and minivans, winter tires produced better acceleration (more precisely, less distance required to reach a speed of 50 km/h). The winter tires yielded even better results in the tests where the temperature was -20 degrees Celsius (Fournier 2001).

In a demonstration project comparing the effectiveness of winter tires versus all-season tires for automobiles (Tire Rack 2007a), a car equipped with winter tires took eight seconds (or 27.3% less time) to reach a distance of 60 metres compared to 11 seconds for a car equipped with all-season tires. In a braking test (from 50 km/h to a full stop), the car with winter tires took 18 metres to stop whereas the car with all-season tires took 27.1 metres (33.6% less distance or a two car-lengths difference). And in a cornering comparison where both cars had to make a 90-degree turn at 40 km/h, only the car equipped with winter

tires was able to complete the turn. Although both cars were equipped with dynamic stability control, the tires' traction limits were exceeded for the car with all-season tires.

In a second demonstration project comparing the effectiveness of winter tires versus all-season tires on sport utility vehicles (SUVs) and light trucks (Tire Rack 2007b), a vehicle equipped with winter tires took six seconds to reach a distance of 60 metres compared to eight seconds for the vehicle equipped with all-season tires (25% less time). In a braking test (from 50 km/h to a full stop), the vehicle with winter tires took 18.6 metres to stop whereas the vehicle with all-season tires took 31.1 metres (40.2% or an additional 2.5 car-lengths to stop). And, once again, in a cornering comparison where both SUVs were required to make a 90-degree turn at 40 km/h, only the vehicle equipped with winter tires was able to complete the turn.

For both types of vehicles tested, Tire Rack determined that all-season tires provided adequate traction in areas receiving occasional light snow. However, it was concluded that only a matched set of four winter tires will cope with deep or frequent slush, snow or ice. Using just two winter tires was not seen as a sufficient measure (Tire Rack 2007a; 2007b).

In a more recent demonstration project performed by Tire Rack using automobiles to compare winter tires and all-season tires, a local skating rink served as a venue to test the acceleration, braking and cornering abilities of the different tires. The car equipped with winter tires took 4.5 seconds to reach 18 metres, compared to 6.0 seconds for the car using all-season tires (25% less time). When measuring the braking distance it would take for a car to stop after reaching speeds of 20 km/h, the car with winter tires needed 10.7 metres to come to a stop as opposed to 16.3 metres for the car with all-season tires (34.4% less distance). And the car with winter tires was able to negotiate a 90-degree right turn at 18 km/h compared to the car with all-season tires that could only manage this manoeuvre at a speed of 13 km/h (Tire Rack 2011a).

With temperatures just below freezing and on dry pavement, stopping distance for vehicles equipped with all-season tires is 30% longer than for vehicles with winter tires. Furthermore, the winter tire has better traction on a snowy surface at temperatures of -40 degrees Celsius than an all-season tire has at +4 degrees Celsius (Mahler 2008a). Even on dry pavement, the overall performance of an all-season tire declines as the temperature becomes colder (Fountain Tire 2011). In a demonstration conducted by the Rubber Association of Canada in partnership with Transport Canada and the Automobile Protection Agency, winter tires consistently outperformed all-season tires on a snow-packed ice surface track near Ottawa (Rubber Association of Canada 2007b).

A demonstration project conducted by the National Law Enforcement and Corrections Technology Center (NLECTC) compared the effectiveness of winter versus all-season tires by using RCMP police cars as test vehicles in Saskatchewan (NLECTC 2006). The winter tires consistently outperformed the all-season tires. Tests also showed that even winter tires with just 50% of their normal tread depth delivered superior performance in snow compared to the all-season tires (Falcon 2005).

Canadian Tire tested the stopping ability of vehicles equipped with winter and all-season tires that were required to brake after reaching speeds of 60 km/h. In this demonstration project, a vehicle equipped with winter tires required 18 fewer metres to stop than did the vehicle using all-season tires. And when testing on ice where the vehicles were required to stop after reaching speeds of 24 km/h, the vehicle with winter tires took from a half to a full car length less distance to stop than did the vehicle with all-season tires (Canadian Tire 2011b).

One study that raises concerns about the use of ratings systems for winter tires was conducted by Transport Canada in 2008. An SUV travelling at 16 km/h was measured for braking distance. Three alpine-rated winter tires were tested. The first vehicle's stopping distance was measured and the first set of tires was given a score of 100. The two other vehicles' stopping distance was measured against the first vehicle and their tires were given scores of 93 and 103, meaning that the second vehicle used 93% of the braking distance of the first vehicle, and the third vehicle used 103% of the braking distance of the first vehicle. Three sets of all-terrain tires were then evaluated. As expected, the first all-terrain tire (without the snowflake logo) was given a score of 140 (40% longer than the vehicle with the first set of winter tires tested). The next two all-terrain tires tested (both winter approved), received scores of 153 and 141 respectively. Thus, two sets of all-terrain winter approved tires had an inferior score and longer braking distance than the first set of all-terrain winter tires that did not meet industry standards to be approved as winter tires (Mahler 2008b).

In Blainville, Quebec, an experimental study indicated that all-season tires outperform winter tires in summer conditions. In +20 degrees Celsius on a dry surface, for braking tests conducted for vehicles travelling at speeds of 50, 70, 90 and 110 km/h, the average braking distance was 2.4 metres (or 9.8%) longer for a vehicle equipped with winter tires than for a vehicle equipped with all-season tires. On wet pavement, the difference was more pronounced as a vehicle equipped with winter tires took 11.9 metres (or 26.2%) longer to stop as opposed to a vehicle with all-season tires (CAA Quebec 2005).

Winter tires versus all-season tires versus summer tires. In a demonstration project performed on an icy surface, winter, all-season and summer tires were placed on a car equipped with ABS brakes. When cars were measured for the amount of time needed to cover 18 metres, the car with winter tires completed the task in 4.5 seconds, compared to 6.5 seconds for the car with all-season tires and 7.4 seconds for the car with summer tires. The car with winter tires needed 6.4 metres to stop after it had reached a speed of 16 km/h, as opposed to 12.1 metres for the car with all-season tires and 14.3 metres for the car with summer tires. A corner test was carried out in which the cars were required to negotiate a 90-degree turn at a speed of 16 km/h. The car with winter tires passed the test, the car with all-season tires initially managed to turn successfully, but later lost control and the car with summer tires lost traction shortly after starting the turn (Tire Rack 2008).

An American experimental study evaluated the performance of different types of tires on different surfaces (Edmunds 2009). On a snowy surface in Baudette, Minnesota, a car equipped with winter tires needed

11.7 seconds to accelerate from 0 to 65 km/h, compared to 14.5 seconds for a car with all-season tires, and 41.7 seconds for a car with summer tires. When testing the distance needed to stop for an ABS-equipped vehicle travelling at 65 km/h, a car equipped with winter tires took 47.6 metres, a car with all-season tires needed 56.1 metres, and a car with summer tires needed 107 metres.

On a wet surface at a proving ground near Phoenix, Arizona, cars equipped with summer tires, winter tires and all-season tires required 11.9, 12.7, and 15.4 seconds respectively to accelerate from 0 to 96 km/h. For a car equipped with ABS brakes to stop on wet pavement after reaching speeds of 96 km/h, the car with summer tires took 47.9 metres, the car with winter tires needed 55.2 metres, and the car with all-season tires needed 65.5 metres. On a dry asphalt course in Fontana, California, cars with summer tires and all-season tires each took 8.7 seconds to accelerate from 0 to 96 km/h, similar to the 8.9 seconds required for the car equipped with winter tires. In a braking test for ABS-equipped cars that had to stop on dry pavement after reaching speeds of 96 km/h, the car with summer tires took 36.6 metres, the car with all-season tires needed 39.9 metres, and the car with winter tires needed 47.2 metres. The winter tire's less than stellar performance on the dry surface was compounded by higher noise levels (Edmunds 2009).

Winter tires versus summer tires. In a demonstration project, TyreSafe compared the braking performance of winter tires and summer tires on snowy and icy roads. Vehicles were measured for distance required to stop after reaching speeds of 30 km/h. On snowy roads, a vehicle equipped with winter tires needed 35 metres to stop compared to 43 metres for a vehicle with summer tires (22.9% less distance). On icy roads, the vehicle with winter tires stopped at 57 metres compared to the vehicle with summer tires, which stopped after 68 metres (19.3% less distance) (TyreSafe 2011).

Four winter tires versus two winter tires. Some drivers try to save money by using only a pair of winter tires and a pair of all-season tires instead of investing in a complete set of four winter tires. Using a pair of front-wheel drive cars in a demonstration project, Tire Rack outfitted one vehicle with four winter tires and put two winter tires on the front and two all-season tires on the back of a second vehicle for a series of tests on ice. In an acceleration test where the amount of time was measured that took each car to reach 18 metres, the car with the matched tires took 4.5 seconds, 0.2 seconds more than the car with the mixed pairs of tires (4.7% more time). However, the distance the vehicle with the mixed pairs of tires needed in order to brake after reaching a speed of 20 km/h was 12.2 metres. The braking distance for the car with the four winter tires was 10.7 metres (12.3% less distance). Furthermore, in a test requiring a vehicle to make a 90-degree turn, the car with the four winter tires completed this manoeuvre successfully at a speed of 18 km/h whereas the vehicle with the mixed set of tires spun out of control (Tire Rack 2011b).

Transport Canada also does not recommend using only two winter tires, since by using four winter tires, vehicle control and stability in slippery conditions are improved. Mixing tires with different tread patterns, internal construction and size compromises vehicle stability (Fountain Tire 2011).

Premium winter tires versus economy winter tires. In Germany, a demonstration project of braking performance of winter tires was conducted on wet pavement. Premium winter tires' braking distance was compared with that of economy winter tires. Braking after reaching speeds of 80 km/h, the vehicle with a premium set of tires took 39 metres to stop compared with 52 metres for the vehicle equipped with economy winter tires (25% less distance) (Topp and Niewöhner 2008).

Summary of experimental studies and demonstration projects. Based on the available information from experimental studies and demonstration projects, it appears that in winter driving conditions, modern winter tires outperform all-season tires and summer tires in most cases. Of the known experimental studies performed with different vehicles on various surfaces, winter tires outperform all-season tires in terms of traction, cornering and braking. With regard to braking comparisons in particular, the differences in stopping distances could be sufficiently significant to avoid a collision.

Epidemiological Collision Studies

There are not many epidemiological collision studies available. For example, with the advent of all-season tires in the early 1980s, it was suggested that perhaps there would be an increase in winter casualty collisions as a result. After a thorough library and online search, there were no reports or articles found that addressed this issue.

Specific evaluation of non-studded winter tires is somewhat limited in that Quebec is the only jurisdiction in North America that requires winter tires to be used by drivers during winter months throughout the jurisdiction as a whole. In this section, the studies have been categorized geographically and include those from Canada, Sweden, Norway, Finland and Japan.

Canadian studies. Since mandatory winter tire legislation has only been in effect since December 2008 in Quebec, a significant amount of data is not available to compare collision frequencies before and after winter tire legislation took effect. In a Transports Québec study (2011), an average of 822 persons were killed or seriously injured during the winters of 2003/2004 to 2007/2008 compared to an average of 523 persons killed or seriously injured during the winters of 2008/2009 and 2009/2010. This is a 36% reduction in persons killed or seriously injured. In Montreal, an average of 153 persons were killed or seriously injured during the winters of 2003/2004 to 2007/2008 compared to an average of 85 persons killed or seriously injured during the winters of 2008/2009 and 2009/2010. This represents a 44% reduction in the number of persons killed or seriously injured in Montreal.

However, while these results are telling, conclusions from this study could be strengthened by comparing the results to changes in crashes in other comparison jurisdictions. Also, it is not clear whether control variables were taken into consideration for variability of winter conditions (e.g., average snowfall, days of inclement weather). On the other hand, an earlier paper mentioned that the average snowfalls in Montreal and Quebec City were greater in the winter of 2008-2009 than they were for the winters of 2003-2004 to 2007-2008 (Fournier and Bélanger 2010). Furthermore, just like with alcohol impaired crashes it is

possible that the reduction in winter driving related-crashes may be due in part to a Canada-wide trend that has seen a drop in the absolute number of persons killed and seriously injured in the past decade. For example, in Canada, TIRF reported 3,909 fatalities in 2003 compared to 2,575 in 2009 which is a reduction of 34.1% (Mayhew et al. 2005, 2011). Without further research it is impossible to completely rule out such alternative explanations. In other words, while the available research does suggest there have been reductions in crashes, it is not clear what portion of these reductions can be directly attributed to the usage of winter tires.

A 2005 Canadian Press study conducted by Leger Marketing revealed that in Ontario, where 29% of drivers use winter tires, 26% of winter collisions are attributed to the absence of winter tires (National Resources Canada 2007).

Transports Quebec estimated 38% of winter collisions involved at least one vehicle fitted with all-season tires during the winter of 2004-2005 (Fournier and Bélanger 2010). It was suggested, therefore, that vehicles equipped with all-season tires were overrepresented in collisions since 90% of passenger vehicles being driven were equipped with winter tires in Quebec even before the 2008 law came into effect.

Swedish studies. One of the earliest studies to compare the performance of studded tires versus summer tires was conducted in Sweden from December 1989 to February 1990. It was reported that studded tires reduced the risk of a road accident on slippery road surfaces by 20-50% compared to summer tires (Junghard 1992).

After a winter tire law was passed in Sweden in 1999, a study was conducted to evaluate the effectiveness of the legislation. Collision rates were compared for winter months when winter road conditions prevailed for the pre-legislation period (1997/98 and 1998/99) and post-legislation period (1999/2000 and 2000/2001). There was an 11-14% reduction in collisions, and an 8% reduction for injury collisions. It was further estimated that the law resulted in 7-9 fewer fatalities and 49-63 fewer serious injuries (Öberg et al. 2002).

A subsequent study claimed that if studded tire use were reduced from 70% to 50% on the entire national road network in Sweden, the estimated number (per winter) of police reported injury accidents would increase by 56 cases. The number of deaths and serious injuries would increase by 1.8 persons and 13.1 persons respectively. For a reduction to 20% usage, the number of accidents will increase by 140.3 cases. The number of deaths and serious injuries would increase by 4.4 and 33.0 persons respectively (Öberg and Moller 2009).

Norwegian studies. A 2011 study by the Institute of Transport Economics focused on the accident rate during winter months in various Norwegian cities between January 2002 and August 2009. They noted that there was an increase in collisions by 10% when the use of studded tires was reduced from 70% to 35% of drivers (Elvik and Kaminska 2011).

Finnish studies. In a study conducted in Southeastern Finland (adjacent to Russia), it was found that the highest collision season for foreign drivers in Finland was winter. Among Finnish drivers, summer was the season with the highest collision rate. One of the contributing factors for overrepresentation for foreign drivers in winter collisions in this region was the non-use of winter tires by Russian motorists (Leviakangas 1998). At the time of this study, and at present, winter tires are required in Finland during winter months but no such regulation exists in Russia. As a consequence, the Finnish Border Guard turn back many Russian cars attempting to enter Finland due to their lack of adequate tires (Helsingin Sanomat 2011).

Japanese studies. Japan banned the use of studded tires in 1990. In a study comparing the 1989/1990 to 1991/1992 winter skidding collisions in Hokkaido versus those which occurred for the winters of 1992/1993 to 1999/2000, it was discovered that no matter what the temperature was, there were on average more skidding collisions in the post-ban period than the pre-ban period (Asano and Hirasawa 2003). The increase was attributed largely to the ban on studded tires which came into effect in 1990. It was argued that non-studded tires buffed snowy and icy road surfaces into an extremely slippery state (Hirasawa and Asano 2003).

Finally, some differences between studded and non-studded winter tires may be attributable to factors other than the physical characteristics of the tires. Kallberg et al. (1996) mentioned that drivers who do not use studded tires do more of their driving in urban areas and accumulate more traffic offences than drivers who use studded tires. On the other hand, in their analysis of previous studies, Kallberg et al. state that drivers with studded tires drive faster than drivers whose vehicles were equipped with non-studded winter tires. Similarly, in a more recent study in Norway, Angelov (2003) concluded that studded tires are only marginally more effective than other winter tires since drivers using studded tires may drive faster.

Literature Reviews

Each of the existing literature reviews that were examined were concerned with studded versus winter tires. When analyzing differences between studded and winter tires, there are behavioural considerations. Drivers with winter tires drove slower than those with studded tires and they also maintained a longer safety margin to the car in front. The changes, however, were not sufficient to keep the crash risk at the same level as those drivers using studded tires (Leppänen 1996).

In a meta-analytical study of eleven previously published studies dealing with studded tires, large variations were found in collision rates on snow or ice-covered roads ranging from a 4% to 72% reduction. On bare roads, the change in collision rates ranged from a 68% decrease to a 151% increase (Elvik 1988). One explanation of the disparity in the data is that earlier studies from the 1970s revealed a much greater reduction in collision rates for users of studded tires than later data showed. The gap between collision rates of vehicles with studded and non-studded winter tires narrowed as worldwide regulations limited the aggressiveness of studs and technological improvements to non-studded winter tires improved their frictional characteristics (Scheibe 2002). When Scheibe researched tire performance for the State of Washington, he noted that studded tires offer the best traction at near freezing temperatures. However,

they are more prone to lose traction at lower temperatures than do non-studded or all-season tires. He also observed that the precise conditions under which studded tires provide significantly better traction than winter tires are rare.

Angelov (2003) compared the effectiveness of studded tires versus non-studded winter tires and reported that non-studded tires offer friction rates comparable to studded tires. And in a 2009 Lithuanian study, it is suggested that on wet surfaces and snow-covered asphalt, braking performance for a car with non-studded tires is better than for a car with studded tires since there is more rubber in contact with the road surface (Mitunevicius et al. 2009).

Researchers from the University of Alaska Anchorage reviewed 19 previous studies from 1970 to 2002 that evaluated collision data for drivers using studded and non-studded winter tires. Included in their analysis was a 1978 study conducted in Michigan and Minnesota which concluded that drivers using studded tires were less likely to be injured than those using non-studded winter tires. However, they also found evidence from an Ontario study which concluded that studded tires did not offer any safety advantages in comparison with winter tires (Zubeck et al. 2004). Overall, the researchers found that studded tires reduce collision risk, yet because of advancements in tire and vehicle design, research from the 1970s was deemed not very applicable to today's situation.

Public Opinion Polls

It is believed that the topic of winter tire use may not receive a lot of attention because the public does not know much about this product. The knowledge gap is clearly illustrated by results of public opinion polls. For example, a Canadian Tire survey found that 50% of respondents did not use winter tires because they believe their regular tires provided sufficient traction (Ipsos Reid 2010). Similarly, in a Harris/Decima poll, among Canadians using winter tires, 58% stated that they change over to winter tires at the first snowfall, frost or loss of driving control incident instead of changing tires when temperatures drop to +7 degrees Celsius (Goodyear Canada 2011).

In a 2009 survey conducted among Canadian Automobile Association (CAA) members, 32% of respondents strongly supported, 29% somewhat supported, 20% somewhat opposed, and 19% strongly opposed mandatory winter tire legislation. Respondents from Alberta (13%), Manitoba (14%), and Ontario (16%) were less inclined to strongly support legislation, as opposed to 66% of respondents from Quebec. By this point, mandatory winter tire legislation was already in place in Quebec. It should be noted that in Atlantic Canada, where none of the four provinces have mandatory winter tire legislation in place, 52% of respondents strongly supported such legislation (CAA 2009).

Political leaders as well as the public at large are divided on the issue of winter tire legislation. In a close vote at a Municipalities Newfoundland and Labrador convention in 2008, 109 municipal leaders voted in favour of requesting provincial introduction of mandatory winter tire legislation while 102 voted against such a measure (Canadian Broadcasting Corporation 2008).

Cost is frequently a barrier that some consumers cite against purchasing winter tires. They report that it is more costly to alternate between winter and summer tires than it is to use all-season tires year-round. A Canadian Tire study found that 41% of respondents who did not use winter tires felt that it would be too expensive to buy a set (Ipsos Reid 2010). However, a Swiss study comparing winter tires and all-season tires concluded that alternating summer and winter tires throughout the year resulted in a reduction of 5% in fuel consumption and 10-15% in mileage performance as opposed to using all-season tires throughout the year (Continental Corporation 2009). Furthermore, if a set of winter tires prevents a collision, the driver has saved the cost of a deductible, which is likely to cost more than a set of winter tires (Guttormson 2010). It would seem that immediate costs receive greater consideration in decisions to purchase winter tires rather than longer-term potential cost savings.

Another obstacle that consumers cite as discouraging them from purchasing winter tires is perceived inferior performance of these tires in delivering fuel economy. However, it has been argued that summer tires wear out more quickly in winter conditions and that by not switching to winter tires, a driver reduces gas mileage by 20% (TyreSafe 2011). And a Nokian Tyres bulletin admits while winter tires may play some role in diminished fuel economy in the winter, additives in winter gas (that minimize fuel tank condensation, clean fuel systems, and expedite evaporation) are more likely to compromise engine performance. A measure of tire performance is rolling resistance. If this can be decreased, fuel is conserved and CO^2 emissions are reduced. Nokian claims that one of their winter tires, the Hakkapeliitta R, has a lower rolling resistance than many of their competitors' all-season fuel-efficient tires (Nokian Tyres 2011). No objective data, however, are available to substantiate this statement. Nevertheless, it again appears that consumers focus more on the shorter-term, more immediate aspects of tire use and not on longer-term potential cost savings.

Consumers with four-wheel drive vehicles may feel that they have no need for winter tires. While it is quite possible that acceleration in winter conditions with all-season tires may not be affected, once the driver makes a sudden swerving or stopping manoeuvre, the all-season tires will not provide the required grip (Canadian Tire 2011b). This could explain why a disproportionate number of 4X4s and SUVs are off the road in early season storms (Nokian Tyres 2011). These vehicles also generally have greater rollover potential due to a higher centre of gravity so losing control could potentially have more severe consequences.

The perceived inconvenience of changing to winter tires in the fall and back to summer tires in the spring may serve as a deterrent to using winter tires for some consumers (www.autos.ca 2003). In a 2010 poll, 27% of non-users of winter tires mentioned that the inconvenience of changing tires was one of the contributing factors (Ipsos Reid 2010).

The Alberta Motor Association (AMA) suggested that difficulty associated with tire selection could also inhibit winter tire use since consumers were given many options when considering what type of tires to purchase for vehicle use during winter months (AMA 2011).

Public opinion on winter tire use can be summarized by stating that among non-winter tire users, cost is a key factor in the decision not to buy winter tires, followed by perceptions that they are neither necessary nor convenient. The public appears to place a greater value on short-term over long-term savings.

Websites, Bulletins, Newsletters, Newspapers and Magazine Articles

Other sources used to augment the literature review of research were newspaper and magazine articles, online bulletins, literature from tire companies, government departments and insurance companies. Generally speaking, findings from these sources are more anecdotal and appear to be in line with findings from scientific studies.

Summary of Literature Review

To summarize, a review of existing literature (primarily since 1985) was performed. Generally speaking, in winter driving conditions, winter tires are superior to all-season tires and summer tires according to experimental studies and demonstration projects. However, there is an insufficient body of literature, notably epidemiological collision studies, to validate this in terms of how these findings translate in the real world. More precisely, the question whether this apparent advantage of superior performance of winter tires in winter conditions translates into fewer collisions, injuries and fatalities requires further investigation, especially in light of recent and continuous improvements to winter tire technology. Much of the earliest available research deals with the effectiveness of studded tires. In more recent years, as studded tire use has declined, more studies have been conducted which review the effectiveness of non-studded winter tires. However, as stated, more research is needed to better understand and measure differences in effectiveness of available types of tires under various road conditions. It is important to note that Quebec undertook its own research on the matter and other jurisdictions are encouraged to build upon this.

LIMITATIONS

There are several factors which inhibit a comprehensive comparison of the effectiveness of different types of tires. These factors are briefly described below.

Outdated Nature of Research Materials

Much of the material reviewed is out of date. The bulk of the available literature comes from 1970 to 2002 and most reports deal with the use of studded tires. This may have important implications for decision-making because improvements made to non-studded winter tires in the past 10-15 years (cold-resistant rubber compound and aggressive treads) mean that the merits of studded tires versus non-studded tires may be overrated. In addition, regardless of the type of tires used, collision rates in general have changed during this period as well and this factor must be taken into consideration.

Limited Data Comparability and Compatibility

Since the introduction of the mandatory winter tire law in Quebec in 2008, there has been an apparent decrease in casualty collisions. However, as mentioned previously, this important study could be further strengthened by adding a control group (e.g., Ontario or any other jurisdiction comparable to Quebec but without a mandatory winter tire law).

Generally speaking, unlike research conducted in a controlled environment, studies examining collision rates must consider anomalies such as differences in temperature and weather conditions, road surface conditions, road maintenance, driver experience, vehicle speed, and vehicle steering and control features, which can be very challenging. As such, these characteristics may not be wholly comparable throughout a given study period or across a study group and its control group. For example, drivers without winter tires may compensate their driving technique by driving more carefully. People with worn tires generally travel slower and slow down more in adverse weather conditions (Elvik 1999). Furthermore, senior drivers are generally involved in fewer collisions during inclement weather, possibly due to trip cancellation (Andrey et al. 2003).

Not only is there a lack of comparable collision data, but there seems to be a lack of data compatibility in terms of reporting winter tire use as different measures produce inconsistent results. For example, in a Rubber Association of Canada study of winter tire use, it was reported that 56% of Nova Scotia drivers use winter tires (Turner 2011). However, the province reported that 80% of drivers were using winter tires (Canadian Broadcasting Corporation 2011a). And in Ontario, it was reported that as few as 29% of

vehicles are equipped with winter tires (CanWest 2008). Yet in a poll conducted among Ontario drivers in 2010 by Ipsos Reid, 46% of respondents claimed to switch to winter tires (Ipsos Reid 2010).

Gaps in Data Collection

Specific research showing a correlation between the use of winter tires and a reduction in collisions is limited and most of these studies are outdated. This can be linked to gaps in the collision data that are collected. Table 2 provides a breakdown on how vehicle conditions are reported in collision reports in each Canadian jurisdiction. As can be seen, for variables dealing with the condition of vehicles involved in collisions, the categories are quite vague. An investigating officer may describe tires as a contributing factor to the collision if they are defective, subject to a blowout, or have an inadequate tread. Generally speaking, there are no provisions in collision reports that allow an officer to list the type of tires used by a vehicle. And in Ontario, collision reporting centres are not mandated to collect data on tire use.

This limitation is not restricted to Canada. In the United States, the National Highway Traffic Safety Administration (NHTSA) has maintained a Fatality Analysis Reporting System (FARS) database that has fatal collision data as far back as 1975. There are values in collision, vehicle and driver-related variables that deal with "equipment failure (blown tire, brake failure, etc.)", "improper tire pressure", and "tire blow-out or flat", but none dealing specifically with using a particular type of tires (NHTSA 2010). In Sweden, police also do not record tire type when filling out collision reports (Öberg et al. 2002).

Table 2: Role of Tires in Contributing Factors on Collision Report Forms

Jurisdiction	Number of Contributing Factors per Vehicle Involved	Value Labels Mentioning Tires as a Factor
BC	4 for all factors	tires- failure/inadequate
AB	1 for vehicle condition	tires failed
SK	4 for all factors	defective tires/tire blowout
MB	3 for all factors	defective tires
ON	1 for vehicle condition	tire puncture/blow out; tire tread insufficient
QC	2 for all vehicles involved	crevaison
NB	4 for all factors	defective tires
NS	4 for all factors	tires
PE	4 for all factors	defective tires
NL	4 for all factors	defective tires
YK	4 for all factors	defective tires/tire blowout
NT	1 for vehicle condition	tire failure/inadequate
NU	1 for vehicle condition	tire failure/inadequate

Inattention to Winter Tire Issue

Not many studies exist on the issue of winter tires. To illustrate, The UMTRI Library catalogue yielded 780 references for impaired driving, 201 for distracted driving, and only 42 for winter tires. Among those 42 citations, only 22 had a publication date from 1985 to 2011. Using Google Scholar to search for articles on winter tires yielded 510 results (466 since 1985, and only 318 if articles about studded tires are omitted), compared to 10,194 for impaired driving, and 1,496 for distracted driving. In the Library of Congress Catalogue there were 93 citations located by using the keywords impaired driving as opposed to 12 for distracted driving and only eight for winter tires (see Appendix 1 for an overview of citations by year).

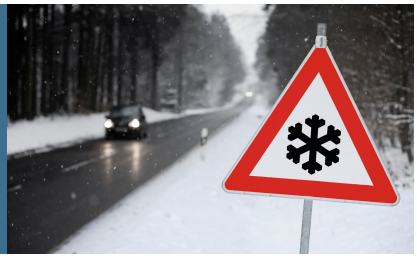
Another factor that leads to a lack of attention to winter tire use is the apparent lack of replication of findings in the studies conducted. Among the literature reviews conducted, a lack of uniformity exists in the findings since some of the reviews included studies performed over a long period of time. Of the few experimental studies evaluating the performance of winter tires versus all-season tires, there is some replication of findings. Yet in a recent study of the stopping distances of different types of non-studded winter tires, researchers found a large variance in the performances of different types of tires. They recommended performing standardized tests in an enclosed building with climate control since some field tests were compromised by unstable conditions (Engström et al. 2009). Similarly, among epidemiological crash studies, there does not appear to be significant replication of findings either.

Lastly, a lack of attention to winter tire use could possibly be explained by a lower rate of casualties in traffic collisions during the winter. The public may believe that winter is a dangerous time to drive compared to the rest of the year. However, according to NHTSA, summer fatality rates in motor vehicle collisions are higher than winter rates (Center for Excellence in Rural Safety 2010). Transportation agencies and emergency response teams may see an increase in crashes during snow events, yet crashes during these conditions do not appear to be as severe as those which occur during equivalent non-snow events, in part due to reduced driving speeds (Khattak and Knapp 2001). Similarly, Statistics Canada reported a downward trend in fatalities from 1989 to 1997, but the number of collisions on slippery surfaces during the same period remained relatively stable. It has been suggested that new safety features in vehicles are saving lives, but drivers are still losing control of their vehicles at the same rate (Mahler 2007).

Proprietary Nature of Research

Quite possibly some of the research conducted by tire manufacturers on the effectiveness of winter tires is confidential and not yet available to the public. In some instances, research conducted by one manufacturer may not even be known to a second manufacturer as companies try to secure market share in the winter tire market.

WINTER TIRE INITIATIVES



National Initiatives

In 2008, Transport Canada, in collaboration with the Canadian Automobile Association (CAA), published a winter driving pamphlet that provided safety tips for drivers. One of the ten tips provided on the subject of preventing problems before they occur was to install four matching winter tires. The publication also explained the difference between winter tires and mud and snow (M+S) rated snow tires (Transport Canada 2008).

In its literature on fuel-efficient driving, the Natural Resources Canada publication Auto$mart advises that improved traction and reduced slippage from winter tire use not only improves safety but saves fuel (Natural Resources Canada 2007).

And in 2011, Transport Canada, in partnership with the Canadian Automobile Association and Canadian Tire, launched its 2011-2012 winter driving campaign. Included in this campaign was the recommendation to install matching winter tires on all wheels of a vehicle since winter tires outperform all-season tires once the temperature drops to +7 degrees Celsius, whether roads are dry, snow-covered or icy (Transport Canada 2011). Car mirror hangers entitled "Don't Let Winter Take You by Surprise" which list several winter driving tips, including the value of winter tires, will be attached to the interior mirror of vehicles serviced in Canadian Tire's automotive department during the winter months. Transport Canada has also included messages in Canadian Tire flyers and Canadian Tire's various social media and online channels.

Provincial Initiatives

TIRF sent a brief questionnaire to a group of stakeholders from CCMTA. Respondents were chosen from two Standing Committees: Drivers and Vehicles; and Road Safety Research and Policies. Committee members from each of Canada's 13 jurisdictions, plus committee members from Transport Canada were chosen to complete the questionnaire. Respondents were asked:

- Has your jurisdiction collected data on the extent of winter tire use among passenger vehicles (cars, vans, light trucks)?
- Has your jurisdiction compiled any data that compare collision data during winter months for passenger vehicles equipped with winter tires versus vehicles that were not equipped with winter tires?
- Has your jurisdiction conducted or sponsored any research that evaluates the effectiveness of winter tire use?
- Does your jurisdiction intend to introduce legislation/regulations to make the use of winter tires mandatory during winter months?

> Other than regulations and public education and awareness campaigns, does your jurisdiction have any initiatives (in effect or proposed) to promote, encourage or incentivize the use of winter tires?

To date, respondents from 10 different jurisdictions (British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, New Brunswick, Prince Edward Island, the Yukon, and Nunavut) replied to the questionnaire.

Table 3: Responses to Winter Tire Questionnaire to CCMTA Stakeholders

Jurisdiction	Collected data on extent of use of winter tires	Compiled collision data comparing winter vs other tires	Conducted or sponsored research on effectiveness of winter tires	Planning to introduce legislation or regulation regarding winter tire use	Other initiatives in effect
BC	No	No	No	Designated roads require vehicle to use winter tires or carry chains	No
AB	No	No	No	No	No
SK	No	No	No	No	No
MB	No	No	No	No	No
ON	No	No	No	No	No
QC	Yes	Yes	Yes	Already implemented	No
NB	No	No	No	Initiating analysis	No
NS					
PE	Yes	Yes	No	No	No
NL					
YK	No	No	No	No	No
NT					
NU	No	No	No	Yes	No
Transport Canada	No	No	No	No	No

Data collection. As can be seen in Table 3, only Prince Edward Island and Quebec have collected data on the extent of winter tire use among passenger vehicles. And Prince Edward Island and Quebec are the only jurisdictions that have collected data comparing collision rates for vehicles equipped and not equipped with winter tires.

Research. Quebec is the only jurisdiction that has conducted or sponsored research on the effectiveness of winter tires.

Legislative initiatives. Quebec is the only jurisdiction that has mandatory winter tire legislation throughout its borders and there does not appear to be any intention to amend that legislation. In British Columbia, vehicles must be equipped with winter tires or the operator must carry chains to be permitted access on designated roads (principally in mountainous terrain). New Brunswick has initiated an analysis on legislating mandatory winter tire use. The New Brunswick Chief Coroner conducted an inquest into a fatal collision that occurred near Bathurst in January 2008. Eight people died in this collision when their school van slid into the path of an oncoming semi-trailer transport truck. It was revealed that the tires used on the van were worn, all-season tires. One of the recommendations of the inquest was that all vehicles transporting students be fitted with winter tires between November 1 and April 30 (New Brunswick Department of Public Safety 2011a).

Nunavut is considering the introduction of mandatory winter tire legislation during winter months. In 2008, Newfoundland and Labrador was seeking evidence that winter tires were safer than all-season tires, before considering mandatory legislation for winter tire use (Whittle 2008). The New Brunswick Department of Public Safety stated in 2010 that it did not intend to introduce a mandatory winter tire law since it considered such a measure to place an undue financial burden on drivers, particularly those who do not drive when the weather is inclement (McGinniss 2010).

Education and awareness. Several governments have encouraged the use of winter tires. In its press release on winter driving, the first tip offered by the Government of Yukon is for drivers to switch to winter tires once the "weather drops below 0 degrees Celsius and the snow starts falling" (Yukon Department of Highways and Public Works 2011). The Insurance Corporation of British Columbia (ICBC) recommends "snow tires" if one lives in a region with a lot of snow or if one has a job or outside interests such as skiing or other winter sports that require driving in winter conditions. ICBC warns that "all-season tires are not designed for snow or severe winter conditions" (Insurance Corporation of British Columbia 2010a). Similarly, the Ontario government recommends that drivers should consider winter tires if they live and drive in "the snowbelt regions of southern Ontario and throughout the north (Ontario Ministry of Transportation 2011). And in New Brunswick, citizens are urged to install four "snow tires" and not to depend on all-season tires" (New Brunswick Department of Public Safety 2011).

The Alberta Government (2009) urges motorists to replace all-season radial tires with winter tires as they are safer. Nova Scotia's webpage on safe driving tips for the winter mentions the benefits of using "proper winter tires that are in good condition" (Nova Scotia Transportation and Infrastructure Renewal 2011). Similarly, the Northwest Territories link on winter driving recommends that drivers "install good winter tires" (Northwest Territories Transportation 2005). Saskatchewan Government Insurance encourages drivers to switch to winter tires if possible (Filazek 2011). The Manitoba Public Insurance (MPI) website has

a section of driving tips that recommends that winter tires offer the best traction for winter conditions (Manitoba Public Insurance 2011a).

Other jurisdictional initiatives. Winter tire use in British Columbia is only mandatory on designated roads and non-use of winter tires does not affect a customer's insurance coverage or eligibility to make a claim. Nonetheless, ICBC states that non-use of winter tires in a crash where they may have helped could be a deciding factor in the degree to which a customer was at fault (Insurance Corporation of British Columbia 2010b). In 2008, MPI conducted a campaign to emphasize the importance of using winter tires. MPI sponsored a contest called Take Action on Traction which allowed contestants to enter online or complete entry forms at hockey games for the Manitoba Moose, Brandon Wheat Kings, Flin Flon Bombers and Manitoba Junior Hockey League teams. Ten sets of winter tires were offered as prizes (Manitoba Public Insurance 2008).

At this stage of the review process, no indication was found of any initiatives undertaken by jurisdictions to promote winter tire use other than legislation/regulation and public education and awareness campaigns. The Winter Driving Safety Coalition called on the Ontario government to explore ways to encourage the use of winter tires through such incentives as rebates or insurance premium discounts (Kalinowski 2010).

Industry Initiatives

Bridgestone Tires offers a winter driving school in Colorado called the Bridgestone Winter Driving School which offers both behind-the-wheel and classroom training. Part of the classroom curriculum deals with the performance of winter tires compared to that of all-season tires (personal communications with Mark Cox, November 28, 2011).

The Insurance Bureau of Canada (IBC) encourages drivers to use winter tires. Companies such as belairdirect and Desjardins offer a 5% premium reduction for clients who use winter tires (Chevreau 2010). And more recently, CAA Insurance has provided a 5% premium deduction (CAA Magazine 2011). Unfortunately, not all consumers take advantage of this offer. Kanetix, on online insurance quote comparison service reported that 20% of respondents did not take advantage of the winter tire discount that many insurance companies offer (Canadian Insurance 2011).

The Association of British Insurers (ABI) has encouraged drivers to use winter tires and stated that adding winter tires to a vehicle did not count as a chargeable modification. It was reported, though, that many insurance companies had a different interpretation. They claimed that if a policyholder switched to winter tires, this was considered a vehicle modification. Thus, some companies were charging an administration fee, and in some instances, increasing the premium (TyreReviews 2010). More recently, however, the ABI released a statement which included a commitment encouraging winter tire use from member companies whose market share was 90% of the motor insurance market. An accompanying table included information on whether a customer was obligated to inform the insurer that they were putting winter tires

on their vehicles and whether the installation of winter tires affected the amount of coverage provided by the insurer. None of the 67 companies charged an extra premium for winter tire use (ABI 2011).

In Germany, drivers who do not use winter tires and are involved in collisions may be found responsible for the collision (eTyres 2004). In a CAA presentation on winter driving, it is stated that even in a single-vehicle reportable collision that results from sliding off an icy road surface, the crash will be classified as an "at fault" claim with an insurance provider. It is also mentioned that tires are the number one mechanical control device on one's vehicle (Blanchard, n.d.).

Stakeholder groups outside the automotive and tire industry have encouraged greater use of winter tires. In a press release, the Ontario Hospital Association stated that after the first snowfall of each winter, increased casualty collisions lead to greater demands placed upon hospitals, leading to longer emergency wait times, fewer available beds, and added stress on hospital staff, patients and their families. It is suggested in the release that using winter tires would "prevent motor vehicle crashes and save precious health care resources, and lost employment income" (Ontario Hospital Association 2011).

CONCLUSIONS

Based on the available information from experimental studies and demonstration projects it appears that in winter driving conditions, winter tires outperform all-season tires and summer tires. In most of the known experimental studies and demonstration projects performed with different vehicles on various surfaces, winter tires outperform all-season tires in terms of traction, cornering and braking. With regard to braking comparisons in particular, the differences in stopping distances could be sufficiently significant to avoid a collision.

Also, based on available public opinion research about winter tire usage, it appears the public does not fully appreciate the benefits of winter tires, suggesting education may be beneficial. Consumer beliefs that discourage greater use of winter tires include the extra cost of buying winter tires, the belief that one's current set of tires is sufficient to cope with winter driving or that the winters where one lives are not severe enough to warrant the use of winter tires. In addition, consumers also believe that safety features such as ABS brakes, electronic stability control and all-wheel or four-wheel drive negate the need for winter tires, and that winter tires compromise fuel efficiency. Some also believe that only two winter tires are needed instead of a set of four.

However, some research suggests that using winter tires is, in the long-term, less expensive than using all-season tires. Alternating between winter and summer tires not only provides better fuel economy than using only all-season tires, but the superior performance of winter tires during winter conditions gives drivers an increased likelihood of avoiding a costly collision. Also, the more resilient compound of winter tires is beneficial when the air temperature is +7 degrees Celsius or lower, regardless of whether the roads are dry, wet, snow-covered or icy. While several Canadian regions may not encounter a lot of snow, most of the country has winter temperatures consistently as cold as, or colder than +7 degrees Celsius during the winter season. Furthermore, while ABS brakes and electronic stability control can certainly reduce the likelihood of a driver losing control of their vehicle, without sufficient traction (which is improved by using winter tires), such safety features are compromised. Finally, the assumption that a vehicle only needs two winter tires instead of a complete set of four seems to be erroneous based on experimental studies as using tires that are of different treads and compounds can cause a vehicle to fishtail. It is for such reasons that some insurance companies offer discounts when using winter tires.

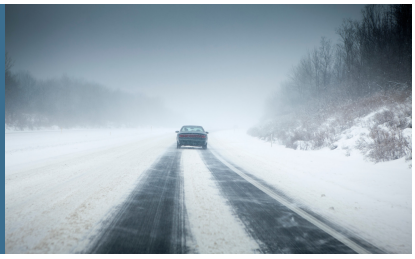
However, despite the apparent advantages of using winter tires, most of the research available about this topic is outdated and fairly limited. More precisely, more research is needed to validate the limited experimental findings and study how these experimental findings carry over into the real world. The

question whether this apparent advantage of superior performance of winter tires in winter conditions translates into fewer collisions, injuries and fatalities requires further investigation.

The issue is compounded by the fast and continuous improvements to winter tire technology in recent years. While more studies focusing on the effectiveness of modern, non-studded winter tires may become available, findings can still be considered limited and more research is needed to better understand how this new technology can help improve traffic safety. As it stands today, more research would be beneficial to further inform sound decision-making.

Finally, it is important to recognize that proper use of winter tires is only one aspect of safe winter driving. There are many other aspects that are important including overall vehicle preparedness and defensive driving techniques. While such aspects were beyond the scope of this report, the findings described in this report are not meant to, and therefore must not be used to limit the discussion of safe winter driving to the use of winter tires only.

RECOMMENDATIONS



Based on the findings from the literature review and environmental scan, the following recommendations have been formulated.

Additional research should be conducted to provide a more comprehensive, up-to-date, and complete picture of the state of winter tire use in Canada.

Overall, the research available about winter tires is limited. Therefore, replication of established findings using experimental research designs, especially to test recent winter tires is desirable. Nevertheless, the most pressing need with respect to winter tires is validation of such 'experimental' findings. It is recommended a research project using an epidemiological approach be undertaken. An epidemiological study could focus on different aspects, including:

- the impact of usage of winter tires on the overall level of crashes, and;
- the impact of winter tires on the seriousness of crashes.

The effect of the usage of winter tires on the overall level of crashes can be accomplished by comparing collision rates from a jurisdiction with mandatory winter tire usage to collision rates of a jurisdiction without mandatory winter tire usage (e.g., Quebec vs. Ontario). Collision rates in both jurisdictions before and after the introduction of mandatory winter tire usage legislation in Quebec can be compared using a pre/post quasi experimental design or a time series analysis design.

While winter weather is similar in the two provinces, there are significant variations between parts of Quebec and Ontario (e.g., Quebec City vs. Windsor) and within these jurisdictions (e.g. Thunder Bay vs. London or Baie-Comeau vs. Montreal). A study comparing two areas with similar weather (Eastern Ontario vs. Western Quebec or Northern Ontario vs. Gaspé) may reduce the study sample size but make comparisons based on weather conditions easier.

Investigating the impact of winter tires on the seriousness of crashes can be accomplished by comparing collision rates of different severity between two such jurisdictions. Another approach would be to compare crashes of vehicles equipped with winter tires to crashes involving vehicles without winter tires. Such a comparison could be done within one jurisdiction without mandatory winter tire legislation, but information about winter tire usage would obviously be needed. Given that this information is not often collected, the best approach would likely be to conduct a pilot project with a well-defined time frame during which winter tire usage information would be gathered through a dedicated effort.

Once more reliable information about the effect of winter tires on traffic safety levels becomes available, a cost-benefit ratio study could be conducted to estimate, in dollar values, how much savings could be gained by using winter tires, both on an individual level as well as a more general level.

Educating the public about the use of winter tires has the potential to serve as an effective means of increasing their overall use.

In light of the findings regarding the public's perception of winter tires, education about the benefits of winter tires is recommended, provided that the focus is not exclusively on winter tires, but rather on winter tires as one aspect of safe winter driving. It appears many drivers lack information or are misinformed about winter tires. As such, raising awareness among the public may be beneficial. This could include the production and distribution of educational materials, for example focusing on misperceptions and rectifying them. This "myth versus reality" approach could debunk the following myths:

Myth

Regular tires provide sufficient traction in winter.

Reality

Winter tires are superior to summer tires and all-season tires in terms of traction, braking performance and cornering in all winter conditions.

Myth

Winter tires are only useful in regions with lots of snow.

Reality

Winter tires outperform other types of tires during all winter conditions, including dry surfaces, once temperatures drop below +7 degrees Celsius.

Myth

Vehicles with ABS, Electronic Stability Control (ESC), all-wheel (AWD) or four-wheel drive do not need winter tires.

Reality

In winter driving conditions such safety features like ABS, ESC, AWD or four-wheel drive are compromised without the use of winter tires.

Myth

Two winter tires instead of a complete set of four winter tires is sufficiently safe.

Reality

Mixing different types of tires can cause a vehicle to fishtail.

REFERENCES

Alberta Motor Association. 2011. Endorsement of winter tires. Backgrounder. Edmonton, AB.: Alberta Motor Association. August 9.

Andersson, A.K.; and Chapman, L. 2011. The impact of climate change on winter road maintenance and traffic accidents in West Midlands, UK. *Accident Analysis and Prevention* 43(1): 284-289.

Andrey, J.C.; and Mills, B. 2003. Collisions, Casualties, and Costs: Weathering the Elements on Canadian Roads. Toronto, ON.: Institute for Catastrophic Risk Reduction. July.

Andrey, J.; Mills, B. and Vandermolen, J. 2001. Weather Information and Road Safety. Paper Series No. 15. Toronto, ON.: Institute for Catastrophic Loss Reduction. August.

Angelov, E.I. 2003. The Studded Tire- A Fair Bargain? VTI Report no.354A. Linkoping, Sweden: Swedish National Road and Traffic Research Institute. May.

Asano, M. 2005. A study on program evaluation of road maintenance by logic model- in the case of the non-studded-tire policy. Proceedings of the Eastern Asia Society for Transportation Studies 6: 1076-1088.

Asano, M.; and Hirasawa, M. 2003. Characteristics of traffic accidents in cold, snowy Hokkaido, Japan. Proceedings of the Eastern Asia Society for Transportation Studies 4: 1426-1434.

Association of British Insurers. 2011. Winter tyres- The motor insurance commitment. London, England: Association of British Insurers. November 25.

Automobile Protection Association. 2011. 2011-2012 Winter Tire Reviews. Toronto, ON.: Automobile Protection Association.

Autos.ca. 2003. Tire test: Nokian WR "All-Weather Plus". www.autos.ca: July 15.

Aviva Canada. 2011. Auto insurance claims spike dramatically during winter months. Toronto, ON.: Aviva Canada. November 23.

Blanchard, G. n.d. Winter Driving. Canadian Automobile Association.

British Columbia Royal Canadian Mounted Police. 2010. Thinking about winter tires? Terrace, BC.: British Columbia Royal Canadian Mounted Police, North District, Traffic Services. October 13.

Brorsson, B.; Ifver, J.; and Rydgren, H. 1988. Injuries from single-vehicle crashes and snow depth. Accident Analysis and Prevention 20(5): 367-378.

Burfien, J. 2010. Winter tire information: Help customers know when to change over to winter tires. Tire Review: August 9.

Canadian Automobile Association. 2009. Winter 2009 Member Survey.

Canadian Automobile Association Quebec. 2008. Study on the effectiveness of winter tires in summer. CAA Quebec. September.

Canadian Broadcasting Corporation. 2006. Winter tires: Making a comeback. CBC News Online: September 8.

Canadian Broadcasting Corporation. 2008. NL towns push for mandatory snow tire law. CBC News: October 12.

Canadian Broadcasting Corporation. 2011a. Snow tires are best for safe winter driving. CBC News: January 7.

Canadian Broadcasting Corporation. 2011b. Snow tire law gets no traction in Saskatchewan. CBC News: November 18, 2011.

Canadian Insurance. 2011. Four discounts to offer personal auto customers to offset rising rates. Canadian Insurance: July 5.

Canadian Tire Corporation. 2011a. All-weather tires set to conquer the urban jungle this winter driving season. Toronto, ON.: Canadian Tire Corporation. September 15.

Canadian Tire Corporation. 2011b. Winter Tires Buying Guide. Toronto, ON.: Canadian Tire Corporation.

CanWest News Service. 2008. All-season vs. winter tires. CanWest News Service: November 10.

Center for Excellence in Rural Safety. 2010. Survey finds drivers mistakenly believe winter is most dangerous travel time. St. Paul, MN.: University of Minnesota, Center for Excellence in Rural Safety.

Chevreau, J. 2010. How winter tires will save you money. Financial Post: December 9.

Continental Corporation. 2009. Touring Club Schweiz runs comparative test of tyre concepts: All-season tyres are a poor compromise. Hanover, Germany: Continental Corporation. April.

Continental Corporation. 2011. Technical Databook 2011-2012 Car 4X4 Van. Hanover, Germany: Continental Corporation. April.

Corkill, L. 2010. Canadian laws for studded tires. Bellevue, WA.: EHow.com.

Cox, M. 2011. Communication with S. Brown about Bridgestone Winter Driving School, November 28.

Edmunds, D. 2009. Tire test: All-season vs. snow vs. summer. Inside Line: October 26.

Eisenberg, D.; and Warner, K.E. 2005. Effects of snowfalls on motor vehicle collisions, injuries, and fatalities. *American Journal of Public Health* 95(1): 120-124.

Elvik, R. 1998. The effects of accidents of studded tires and laws banning their use: A meta-analysis of evaluation studies. Oslo, Norway: Institute of Transport Economics. December.

Elvik, R. 1999. The effects on accidents of studded tires and laws banning their use: A meta-analysis of evaluation studies. *Accident Analysis and Prevention* 31: 125-134.

Elvik, R.; and Kaminska, J. 2011. Effects on Accidents of Reduced Use of Studded Tires in Norwegian Cities. TOI Report. Oslo, Norway: Institute of Transport Economics. April.

eTyres. 2004. Winter tyres. Cambridge, England: eTyres.

European Commission. 2010. Winter tyres within Europe, in Iceland and Norway. ECC-Net: January 26.

Falcon, W. 2005. Special technologies for law enforcement and corrections. NIJ Journal 252: July.

Falls, L.C.; Jurgens, R.; and Chan, J. 2008. Effect of winter events on highway performance in the Province of Alberta. Paper Number: 08-1886. In: Transportation Research Board 87th Annual Meeting Compendium of Papers DVD. Washington, DC.: Transportation Research Board.

Filazek, T. 2011. DriveRIGHT: Preparation the key to safe winter driving. Regina, SK: Saskatchewan Government Insurance.

Fitzharris, M.;and Corben, B. 1998. A comparison of crash types in Victorian alpine regions during the snow season and outside the snow season, 1987-96: A multi-faceted approach involving GIS technology in assessing the needs of countermeasure development and application on tourist routes. In: Proceedings of Road Safety Research, Policing & Education Conference, Wellington, New Zealand, November, 16-17, 1998, pp. 180-190. Vol. 2. Wellington, New Zealand: Land Transport Safety Authority.

Fountain Tire. 2011. Winter tires 101- winter tire help. Edmonton, AB.: Fountain Tire.

Fournier, L. 2001. Comparative evaluation comparative of the performance of all-season tires and winter tires. Quebec, QC.: Transports Québec.

Fournier, L.; and Bélanger, C. 2010. A new measure making winter tires mandatory in Quebec. Paper presented at the Annual Conference of the Transportation Association of Canada Annual Conference, Halifax, Nova Scotia. Quebec, QC.: Transports Québec.

Goodyear Canada. 2011. Canadians love their winter tires, but wonder what's the rush, according to new Goodyear survey. Toronto, ON: Goodyear Canada. November 7.

Government of Alberta. 2009. Winter driving in Alberta- Safety comes first. Edmonton, AB.: Government of Alberta. December 18.

Gustafsson, M.; Blomqvist, G.; Gudmundsson, A.; Dahl, A.; Swietlicki, E.; Bohgard, M.; Lindbom, J.; and Ljungman, A. 2008. Properties and toxicological effects of particles from the interaction between tyres, road pavement and winter traction material. Science of the Total Environment 393: 226-240.

Guttormson, K. 2010. Are winter tires worth the cost? Ask yourself what an accident will cost. Calgary Herald: November 8.

Helsingin Sanomat. 2011. Tyres on Russian cars still giving cause for concern. Helsingin Sanomat: November 14.

Hirasawa, M.; and Asano, M. 2003. Development of traffic accident analysis system using GIS. Proceedings of the Eastern Asia Society for Transportation Studies 4: 1193-1199.

Horiuchi, K. 1989. Use of studless tires and driver education in Japan. IATSS Research 13(1): 7-16.

Insurance Corporation of British Columbia. 2010a. Driving in poor conditions: Make sure you're prepared. North Vancouver, BC.: Insurance Corporation of British Columbia. October.

Insurance Corporation of British Columbia. 2010b. ICBC responds to questions about winter tires and insurance. North Vancouver, BC.: Insurance Corporation of British Columbia. November 22.

Ipsos Reid. 2010. Winter Driving Research. Final Report. Toronto, ON.: Ipsos Reid; and Canadian Tire. July.

Junghard, O. 1992. Estimating the traffic safety effect of studded tires. *Accident Analysis and Prevention* 24(4): 357-361.

Kalinowski, T. 2010. We deserve snow tire rebate, group says. Toronto Star: December 14.

Kallberg, V.P.; Kanner, H.; Mäkinen, T.; and Roine, M. 1996. Estimation of effects of reduced salting and decreased use of studded tires on road accidents in winter. Transportation Research Record 1533: 38-43.

Khattak, A.J.; and Knapp, K.K. 2001. Interstate highway crash injuries during winter snow and nonsnow events. In: Highway Safety: Modeling, Analysis, Management, Statistical Methods, and Crash Location. *Transportation Research Record* 1746: 30-36.

Kupiainen, K.; and Tervahattu, H. 2004. The effect of traction sanding on urban suspended particles in Finland. *Environmental Monitoring and Assessment* 93: 287-300.

Kuryllowicz, K. 2011. Snow joke: Giving winter tires the cold shoulder can be expensive. Canadian Manufacturing. September.

Laurinavicius, A; Miskinis, D.; Vaiskunaite, R.; and Laurinavicius, A. 2010. Analysis and evaluation of the effect of studded tyres on road pavement and environment (III). Baltic Journal of Road and Bridge Engineering 5(3): 169-176.

Leppänen, A. 1996. The final results of the Road Traffic in Winter Project. Helsinki, Finland: Finnish Road Administration.

Leviakangas, P. 1998. Accident risk of foreign drivers--The case of Russian drivers in South-Eastern Finland. Accident Analysis and Prevention 30(2): 245-254.

Lu, J.J. 1995. Vehicle traction performance on snowy and icy surfaces. In: Transportation Research Record 1536: 82-89.

Lu, J.J.; Junge, D.; and Esch, D. 1994. Winter Tire Traction Evaluations. Fairbanks, AK.: University of Alaska Fairbanks; and Alaska Department of Transportation and Public Utilities. September.

Mahler, J. 2007. Best new winter tires: Choice of seven new models will serve GTA drivers in environment of cold, dry pavement. Toronto Star: November 24.

Mahler, J. 2008a. All-seasons hardly the best choice for Ontario: We all need winter tires (not snow tires), but we don't need legislation to get there- with a few exceptions. Toronto Star: January 26.

Mahler, J. 2008b. New winter tire logo losing market value: Transport Canada tests of alpine-rated winter and all-season rubber show wide results. Toronto Star: March 1.

Mahler, J. 2009. All-weather tires top all-seasons. Toronto Star: May 23.

Manitoba Public Insurance. 2008. Winter driving- Take Action on Traction. Winnipeg, MB.: Manitoba Public Insurance. October.

Manitoba Public Insurance. 2011a. Driving tips- Are you ready for winter's worst? Website safety column. Winnipeg, MB.: Manitoba Public Insurance.

Manitoba Public Insurance. 2011b. Road Safety- Other issues: Winter driving. Website safety column. Winnipeg, MB.: Manitoba Public Insurance.

Mayhew, D.R.; Brown, S.W.; and Simpson, H.M. 2005. The Alcohol-Crash Problem in Canada: 2003. Ottawa, ON.: Transport Canada.

Mayhew, D.R.; Brown, S.W.; and Simpson, H.M. 2011. The Alcohol-Crash Problem in Canada: 2009. Ottawa, ON.: Transport Canada.

Maze, T.H.; Agarwal, M.; and Burchett, G. 2005. Whether Weather Matters to Traffic Demand, Traffic Safety, and Traffic Flow. Ames, IA.: Iowa State University, Center for Transportation Research and Education. August.

McGinnis, K. 2010. New Brunswick not on board for mandatory winter tire law. Auto Industry News.

Mitunevicius, V.; Nagurnas, S.; Unarski, J.; and Wach, W. 2009. Research of car braking in winter conditions. Proceedings of the 6th International Scientific Conference Transbaltica 2009.: 156-161.

Munehiro, K.; Akimoto, S.; Tokunaga, R.; and Asano, M. 2008. Effects of dry and compacted snow on passing behavior in driving test on rural highways. Paper Number: 08-0718. In: Transportation Research Board 87th Annual Meeting Compendium of Papers DVD. Washington, DC.: Transportation Research Board.

Nakajima, Y. 2003. Analytical model of longitudinal tire traction in snow. *Journal of Terramechanics* 40: 63-82.

National Highway Traffic Safety Administration. 2010. FARS Analytic Reference Guide1975 to 2009. DOT HS 811 352. Washington, DC.: U.S. Department of Transportation, National Highway Traffic Safety Administration. August.

National Law Enforcement and Corrections Technology Center. 2006. Over the white and drifted snow. Tech Beat. Spring.

National Resources Canada. 2007. Driver Educator's Newsletter. Volume 4. Winter.

Natural Resources Canada. 2007. Auto$mart Thinking- Driving and Maintaining Your Vehicle. Ottawa, ON.: Natural Resources Canada.

New Brunswick Department of Public Safety. 2011a. 2009 Annual Report. Fredericton, NB.: New Brunswick Department of Public Safety, Office of the Chief Coroner.

New Brunswick Department of Public Safety. 2011b. Winter safety. Fredericton, NB.: New Brunswick Department of Public Safety.

New Brunswick Department of Transportation and Infrastructure. 2011. Winter maintenance costs to be reduced by an estimated $4 million. November 3.

North Stategic. 2011. North Strategic- Canadian Tire. Vision Critical: September 4.

Nokian Tyres. 2011. Nokian Tyres FAQ. Nokia, Finland: Nokian Tyres.

Northwest Territories Transportation. 2005. Six hot winter driving tips. Yellowknife, NT.: Northwest Territories Transportation.

Nova Scotia Transportation and Infrastructure Renewal. 2011. Tips for safe winter driving: Slow down. It's winter. Halifax, NS.: Nova Scotia Transportation and Infrastructure Renewal.

Öberg, G.; and Möller, S. 2009. Hur påverkas trafiksäkerheten om restriktioner av dubbdäcksanvändning införs? Kan en förbättrad vinterväghållning medföra att trafiksäkerhetsnivån bibehålls? (How will a restriction of studded tyre use affect road safety? Could increased winter road maintenance sustain existing road safety levels?). VTI Rapport 6489. Linköping, Sweden: Swedish National Road and Transport Research Institute (VTI).

Öberg, G.; Velin, H.; and Wiklund, M. 2002. Effekt av vinterdäcklagen på däckanvändning och olyckor (The effect of the Winter Tyre Law on the use of tyres and on accidents). VTI Rapport 479. Linköping, Sweden: Swedish National Road and Transport Research Institute (VTI).

Ontario Hospital Association. 2011. Ontario Hospital Association encourages Ontarians to practice safe driving. December 6.

Ontario Ministry of Transportation. 2010. Ontario Road Safety Annual Report 2007. Toronto, ON.: Ontario Ministry of Transportation.

Ontario Ministry of Transportation. 2011. Winter driving: Be prepared, be safe! Toronto, ON.: Ontario Ministry of Transportation.

Padget, E.; Knapp, K.K.; and Thomas, G.B. 2001. Investigation of winter-weather speed variability in sport utility vehicles, pickup trucks, and passenger cars. In: Americans with Disabilities Act; Driver and Vehicle Modelling; Situation Awareness; Licensing; Driver Behavior; Enforcement; Trucks; and Motorcycles. Transportation Research Record 1779: 116-124.

Petro-Canada. 2011. For cold weather starts: Petro-Canada's exclusive WinterGas. Calgary, AB.: www.petro-canada.ca (accessed November 29, 2011).

Piercefield, E.; Wendling, T.; Archer, P.; and Mallonee, S. 2011. Winter storm-related injuries in Oklahoma, January 2007. Journal of Safety Research 42(1): 27-32.

Qiu, L.; and Nixon, W. 2008. Effects of adverse weather on traffic crashes: Systematic review and meta-analysis. Paper Number: 08-2320. In: Transportation Research Board 87th Annual Meeting Compendium of Papers DVD. Washington, DC.: Transportation Research Board.

RBC Insurance. 2008. Canadians not buying into snow tires: RBC Insurance survey. Mississauga, ON: RBC Insurance. November 28.

Robertson, I. 2008. Quebec's snow tire law on right track. Sun Media: December 24.

Rubber Association of Canada. 2007a. Tire basics: What drivers should know about tires. The Autosmart Fact Sheet Series. Mississauga, ON.: Rubber Association of Canada.

Rubber Association of Canada. 2007b. Video illustrates significant benefits of winter tires. Mississauga, ON.: Rubber Association of Canada. December.

Rubber Association of Canada. 2012. (R. Warner, personal communication, January 19, 2012). Mississauga, ON.: Rubber Association of Canada.

Russell, R. 2011. Almost time to roll on winter tires. Globe and Mail: October 11.

Safe Roads Canada. 2009. 42 Ways to be safer this holiday and all winter long. Skid Control School Safety Bulletin Series. Oakville, ON.: Safe Roads Canada.

Scheibe, R.R. 2002. An Overview of Studded and Studless Tire Traction and Safety. WA-RD 551.1. Olympia, WA.: Washington State Department of Transportation. October.

SmartRisk. 2009. The Economic Burden of Injury in Ontario. Toronto, ON.: SmartRisk.

Sokolovskij, E. 2006. Parameters of automobile movement in case of braking and bumping by wheels to the vertical protusion of road covering. Mechanika 57(1): 41-47.

Sonnadara, K. 2011. All-season tires for all winters: Myth or reality? Evergeek Media: November 1.

Strandberg, L. 1998. Winter braking tests with 66 drivers, different tyres and disconnectable ABS. STOP Preprint 981113. Sturefors, Sweden: Strandberg Accident Prevention. November.

Strong, C.; Ye, Z.; and Shi, X. 2010. Safety effects of winter weather: The state of knowledge and remaining challenges. *Transport Reviews* 30(6): 677-699.

1010Tires.com. 2011. The Complete Winter Tires Guide. Richmond, BC.: 1010Tires.com.

Tire Rack. 2007a. All-season vs. winter (passenger vehicle): The difference between wintertime gripping and white knuckle snow slipping. South Bend, IN.: Tire Rack. December.

Tire Rack. 2007b. All-season vs. winter (SUV/light truck): The difference between wintertime gripping and white knuckle snow slipping. South Bend, IN.: Tire Rack. December 28.

Tire Rack. 2008. Testing on ice: Winter/snow vs. all-season vs. summer tires. South Bend, IN.: Tire Rack. February 5.

Tire Rack. 2011a. Are front-wheel drive and all-season tires enough for winter driving? South Bend, IN.: Tire Rack. August 2.

Tire Rack. 2011b. Why gamble with winter tire selection when four of a kind always beats two pair? South Bend, IN.: Tire Rack. August 2.

Topp, A.; and Niewöhner, W. 2008. Crash test: Safety risk cheap imported vs. premium winter tires. Paper presented at the ContiWinter Roadshow, October 13, 2008.

Trang, A. 2010. Examination of Winter Driving Using In-Vehicle Devices and the Perceptions of Older Drivers. Masters Thesis. Waterloo, ON.: University of Waterloo.

Transport Canada. 2008. Winter Driving: You, your vehicle and winter driving. TP14840E. Ottawa, ON.: Transport Canada.

Transport Canada. 2009. Low Rolling Resistance Tires Test Plan. Ottawa, ON: Transport Canada, Environmental Initiatives. February.

Transport Canada. 2011. Don't let winter take you by surprise. Ottawa, ON.: Transport Canada. November 2.

Transports Québec. 2007. Regulation governing the use of tires specifically designed for winter driving. Québec, QC.: Transports Québec.

Transports Québec. 2011a. Mise en oeuvre de la mesure rendent obligatoire l'utilisation de pneus d'hiver pour certains vehicles. Québec, QC.: Transports Québec.

Transports Québec. 2011b. Follow-Up Report: Implementation of a measure making winter tires mandatory for certain road vehicles. Québec, QC.: Transports Québec. June.

Turner, B. 2011. Tread carefully into winter tires: Buy what you need for your type of driving. Ottawa Citizen: October 21.

TyreReviews. 2010a. Is your insurance company being winter tyre friendly? TyreReviews: November 7.

TyreReviews. 2010b. Seven reasons to consider winter tyres. TyreReviews: January 10.

TyreSafe. 2011. Tyre Safety winter tyre safety. Colchester, Essex: TyreSafe.

TyreSafe. 2011. Winter weather tyres and your safety. Colchester, Essex: TyreSafe.

Usman, T.; Fu, L.; and Miranda-Moreno, L.F. 2010. Quantifying safety benefit of winter road maintenance: Accident frequency modeling. *Accident Analysis and Prevention* 42(6): 1878-1887.

Vancouver Sun. 2008. Winter tires a must in Canadian weather: If Canadian Motorsports Hall of Famer Richard Spenard had his way, we would all have winter tires installed on our daily drivers by Hallowe'en. Vancouver Sun: January 29.

Whittle, P.L. 2008. Province cannot get a grip on winter tire issue. Polemic and Paradox: October 16.

Yukon Department of Highways and Public Works. 2011. Winter Driving. October 14.

Zubeck, H.; Aleshire, L.; Harvey, S.; Porhola, S.; and Larson, E. 2004. Socio-Economic Effects of Studded Tire Use in Alaska. Final Report. Anchorage, AK.: University of Alaska. May.

APPENDIX 1

Comparison of Number of Citations on Impaired Driving, Distracted Driving, and Winter Tires by Library Catalogue and Year

Year	UMTRI Library Catalogue			Google Scholar			Library of Congress		
	Impaired Driving	Distracted Driving	Winter Tires	Impaired Driving	Distracted Driving	Winter Tires	Impaired Driving	Distracted Driving	Winter Tires
Before 1985	383	13	20	610	171	44	20	0	5
1985	41	0	3	82	48	2	3	0	0
1986	22	0	0	104	26	1	1	0	0
1987	13	2	0	92	19	2	0	0	0
1988	24	0	0	106	10	0	4	0	0
1989	27	0	0	160	23	1	5	0	0
1990	21	1	1	123	5	6	4	0	0
1991	7	2	0	122	4	0	2	0	0
1992	21	1	0	151	5	1	2	0	0
1993	10	2	3	199	17	1	2	0	0
1994	9	4	4	190	13	2	1	0	0
1995	10	0	4	252	17	4	1	0	0
1996	5	0	0	213	23	23	2	0	0
1997	24	2	1	221	19	17	2	0	0
1998	11	2	3	246	7	10	0	0	0
1999	23	8	1	287	23	10	2	0	0
2000	24	10	1	362	9	14	4	0	0
2001	19	25	1	362	94	15	2	0	1
2002	28	17	0	427	14	15	1	1	0
2003	17	30	0	480	39	33	3	4	1
2004	13	27	0	547	35	26	3	0	1
2005	15	17	0	574	49	31	6	1	0
2006	5	4	0	608	54	32	4	0	0
2007	4	2	0	661	77	35	3	0	0
2008	1	6	0	681	86	41	4	0	0
2009	3	16	0	722	124	63	5	2	0
2010	0	9	0	763	246	42	5	2	0
2011	0	1	0	849	239	39	2	2	0
Total	**780**	**201**	**42**	**10194**	**1496**	**510**	**93**	**12**	**8**

TRAFFIC INJURY RESEARCH FOUNDATION

171 Nepean Street, Suite 200
Ottawa, Ontario, Canada K2P 0B4

Email: tirf@tirf.ca Website: www.tirf.ca
Telephone: (613) 238-5235 Toll Free: (877) 238-5235
Fax: (613) 238-5292

Registered Charity Number: 10813 5641 RR0001