Speed Characteristics on Manitoba's National Highway System Roads Using Weigh-in-Motion Data

Jane MacAngus, EIT[1], Craig Milligan, EIT[1], Jeannette Montufar, Ph.D., P.Eng.[1], Leanna Belluz, P.Eng.[2]

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1. Department of Civil Engineering University of Manitoba
2. Transport Canada

Abstract

Speed characteristics are influenced by many different factors (e.g. road engineering, vehicle classification, temporal factors, and weather factors) and in turn influence various outcomes such as safety, environmental impacts, and road user costs. In order to work towards improved outcomes in these areas, it is important to understand current speed characteristics and how these characteristics vary with influencing factors.

The research leading to this paper had two objectives: (1) to synthesize existing knowledge about speed and factors that either influence speed or are an outcome of speed, and (2) to analyze speed data to determine the vehicle operating speed impacts from different vehicle classifications, temporal factors, environmental factors, and road factors.

The literature review conducted for the synthesis of existing knowledge examines selected publications from the last 10 to 15 years. The speed data is obtained from the Manitoba Highway Traffic Information System (MHTIS) database from five weigh-in-motion (WIM) devices on selected portions of Manitoba's National Highway System (NHS) roads. This database contains nearly continuous year round information and approximately eight million geographically referenced speed records linked to vehicle classification and time of day for the year 2010.

The speed records from the five WIM devices are aggregated together to determine the distribution of vehicle speeds with respect to different influencing factors including: (1) vehicle classification (motorcycles, passenger vehicles, small trucks and buses, single trailer combinations, and multi-trailer combinations), (2) temporal factors (seasonal, monthly, day of week, and time of day), (3) environmental factors (lighting and weather factors), and (4) road engineering factors (divided and undivided highways, and urban and rural highways). The results of the analysis provide a better understanding of speed behaviour under different influencing factors.

INTRODUCTION

Transport Canada is interested in gaining a broader understanding of factors influencing operating speed on National Highway System (NHS) roads. This research is intended to provide Transport Canada with one method that may be used to collect speed data from existing traffic data resources with the potential to be considered in the development of a National Speed Survey methodology.

The purpose of this research is to understand vehicle operating speed distribution as a function of vehicle classification, temporal factors, environmental factors, and road factors; of vehicles travelling on selected portions of Manitoba's National Highway System (NHS) roads. The detailed analysis of speed characteristics is based on a database of speed records developed from five weigh-in-motion stations on NHS highways in the province. The research also involves a literature review of factors that influence operating speed and outcomes influenced by operating speed to provide background on speed issues.

BACKGROUND

Speed is a complex and heterogeneous characteristic of transportation system flows, influenced by many factors, and in turn influencing many outcomes. Factors influencing speed can include road engineering, vehicle classification, temporal factors, weather factors, driver attitude and behaviour, and the regulatory and enforcement environment, among others. Outcomes influenced by speed can include safety, environmental impacts, and road user costs.

Manitoba provincial highways provide an environment where vehicles can operate primarily in an uncongested, uninterrupted flow regime - and this regime exerts a common influence on speed patterns. Topography and land use patterns in the region have resulted in common geometric characteristics for the roads on which most of the travel occurs.

SYNTHESIS OF OPERATING SPEED INFLUENCES AND OUTCOMES

The synthesis of operating speed influences and outcomes consists of a literature review of selected publications from engineering and scientific periodicals and journals, conference proceedings, documents from industry associations and special interest groups, and government reports.

Factors Influencing Operating Speed

The literature review focuses on the following six factors as potentially impacting operating speed: (1) vehicle classification, (2) temporal factors, (3) weather factors, (4) driver attitude and behaviour, (5) regulatory and enforcement environment, and (6) road engineering. Key findings of the influences of these factors include:

Vehicle Classification

Vehicle classification has an impact on resulting operating speed in regards to a vehicles mechanical fitness and capabilities, style of vehicle, and vehicle speed management systems [1, 2]. Restrictions may be placed on certain vehicles such as heavy vehicles for fuel efficiency, environmental purposes, or safety concerns. Heavy trucks and buses are restricted in terms of operating speed for both environmental and safety purposes [3].

Temporal Factors

Temporal factors have the potential to influence operating speed in several ways including driver performance, trip purpose or lighting conditions. Darkness conditions may reduce operating speed by up to five kilometres per hour while in other cases darkness conditions were found to have little impact on resulting operating speeds [4, 5]. In terms of specific days, Sundays, summer time, and vacation periods were found to have lower average speeds when compared to all other days [4].

Weather Factors

Several weather factors can influence vehicular speed. These include rain, snow, wind, visibility, and road surface conditions. Rain was found to impact operating speed in two ways: (1) rain intensity, and (2) road surface condition (e.g. wet, dry). Rain was found to reduce speed by between one and ten kilometres per hour depending on the intensity of the precipitation [6, 7, 8]. Wet surface conditions were found to reduce speed by between 9.5 and 12 kilometres per hour depending on the highway type [4, 9].

Similarly, snow was found to impact speed in two ways: (1) snow intensity, and (2) road surface condition (e.g. presence of snow on road). Reductions in speed ranged from three to 50 kilometres per hour during snowfall conditions and were dependent on the severity or intensity of the snowfall [6, 8]. Reductions in speed ranging from 10 kilometres per hour to 16 kilometres per hour were also found when snow was present on the road surface [9, 10].

Wind speed was found to impact operating speed upon reaching a certain threshold, at which point operating speeds were observed to either decrease or become highly variable [9]. The value of this threshold differs across the literature ranging from 24 kilometres per hour to 48 kilometres per hour – although studies reporting the lower range of this threshold may not adequately separate simultaneous visibility reduction effects that are actually the cause of the speed reduction [6, 9, 10]. Visibility was also found to impact speed upon reaching a specific threshold. One study found that in cases where visibility was less than 0.16 kilometres a speed reduction by more than 14 kilometres per was observed when compared to times when visibility was not an issue [10]. Another study found that when visibility fell below 0.28 kilometres speed was found to decline by 0.77 kilometres per hour for every 0.01 kilometre below the critical value [9].

Driver Attitude and Behaviour

Drivers have different approaches and motives for selecting their personal speed. A driver's attitude on safety trade-offs, perceived risk of being caught speeding, how they value their time, and other factors contribute to their speed selection. Their attitude towards driving and speed selection is reflected in how they operate their vehicle and their overall driving behaviour.

A driver's attitude towards speeding was found to reflect their choice of operating speed with driver's behaviour ranging from those that rarely travel above the speed limit to those drivers considered to be risk takers or socially deviant drivers [11, 12]. The literature found that driver's indicated several reasons for speeding; these included not wanting to be late, not paying attention to the speed limit, believing speed limits are set too low, ego-gratification, and risk-taking [11, 13].

Regulatory and Enforcement Environment

In general, drivers wish to avoid penalties or consequences associated with exceeding speed limits. There are two primary methods of speed enforcement: (1) physical policing, and (2) speed camera enforcement. In terms of physical policing, for greatest results it must be supported by laws, regulations, and a sensitive penal system [14]. Physical policing is more labour intensive than speed camera enforcement and does not achieve the same apprehension levels; however violators face immediate consequences [14].

Resource allocation is important when determining where and when to use speed enforcement. Key considerations include selecting sites, situations and times where speeding has the greatest impact on road safety outcomes, selecting sites with appropriate speed limits, or selecting locations with subjectively high risk [2, 14]. High frequency of enforcement and variation in times and locations is also important for effective enforcement strategies [2, 14]. A key component of compliance with a regulation is that it is a reasonable constraint on behaviour suggesting that the majority of drivers will comply with speed limits voluntarily [15]. Even if reasonable limits are set, enforcement is necessary for those drivers who will obey the speed limit only if they believe there is a possibility of being detected and punished for noncompliance [15].

Road Engineering

Road engineering can impact a driver's choice of speed in a number of different ways including centreline treatments, road geometry (e.g. horizontal and vertical geometry), the roadside environment or the selection and placement of signage. General findings from the literature include; decreased speeds are associated with decreased curve radii [16-18], and increased speeds are associated with increased lane width or driver sight distance [19, 20].

Outcomes Influenced by Operating Speed

Three key outcomes were identified as being impacted by vehicle operating speed: (1) safety, (2) environmental impacts, and (3) road user costs. Key findings on the influence of operating speed on these outcomes include:

Safety

The literature revealed several safety characteristics that are affected by vehicle operating speed. These include the effects of speed with respect to overall traffic speeds and how this relates to the likelihood of collision involvement, the probability of being involved in a collision, and the variability of collision severity at impact.

Several safety studies investigate speed dispersion and how deviating from the average speed may impact the likelihood of collision involvement [15, 21]. One study found evidence that vehicles travelling near the average speed of traffic faced the lowest collision occurrence and the risk increased for those vehicles travelling either much faster or much slower than the average speed [21].

The relationship between speed and the probability of being involved in a collision was found to be inconclusive. Some studies indicated that although it is a common belief that greater speeds result in a higher probability of a collision occurring, it is currently not well supported in the research [15, 22]. Additionally, although high speeds result in larger stopping distance and greater required reaction times, it is difficult to distinguish the impact of speed on collision rates from other contributing factors [23].

Collision severity, however, was found to be related to operating speed at the time of impact as supported by the principles of physics. Damage increases with pre-collision velocity, and this relationship has been amply supported with data [15, 22].

Environmental Impacts

Several harmful pollutants are emitted from motor vehicles including Nitrogen Oxides (NO_x), Carbon Monoxide (CO), Carbon Dioxide (CO_2), Hydrocarbons (HC), and others [24]. These pollutants have been associated with serious health and environmental problems including respiratory ailments, global warming, and ground-level ozone, among others. CO and CO_2 emissions were found to be highest at low speeds and decrease up to approximately 60 to 80 kilometres per hour before increasing again for gasoline fuelled vehicles [7, 25, 26].

Road User Costs

Road user costs are typically associated with vehicle operating costs, such as optimizing fuel consumption while at the same time maintaining a reasonable level of mobility. Operating speed is often a trade-off between fuel and mobility in terms of road user costs. There may be economic and personal benefits to travelling at a higher speed, however, this may result in increased fuel consumption.

In terms of fuel consumption and optimum speed the literature revealed several sources with varying conclusions. One study found the optimal speed for fuel consumption to be between 80 and 97 kilometres per hour [25], while another found the optimal speed to be between 50 and 70 kilometres per hour [27]. Additionally, other studies found the optimal speed for fuel consumption to be 72 kilometres per hour [26] and another 89 kilometres per hour [15]. The fact that speeds this low are rarely observed reveals that in the aggregate, optimization of fuel costs does not play a strong role in speed selection.

SPEED DATA ANALYSIS

The speed data analysis provides an understanding of operating speed distribution as a function of vehicle classification, temporal factors, environmental factors, and road factors. The detailed speed analysis of speed characteristics is based on a database of speed records developed from five weigh-in-motion (WIM) stations on NHS highways in Manitoba. The locations of the WIM devices used in this research are presented in Figure 1.

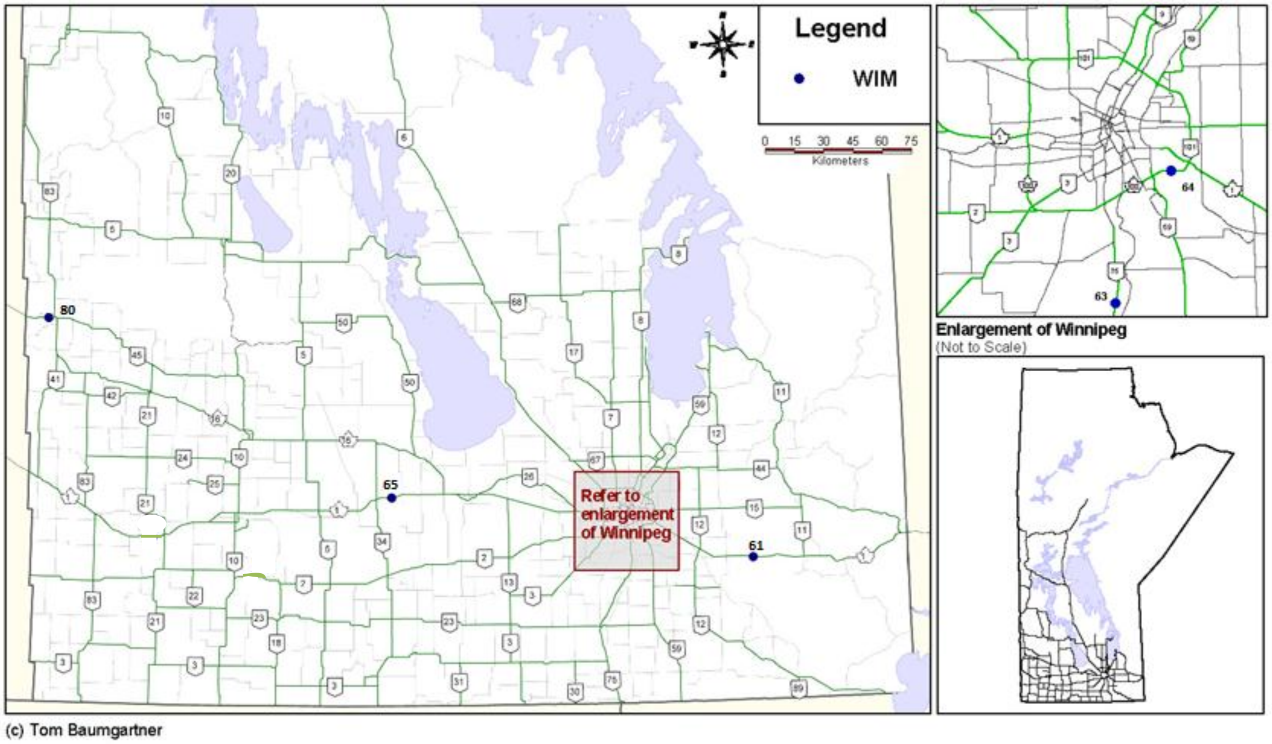


Figure 1: Location of WIM Devices on Manitoba Highways

The speed analysis section of this paper comprises six components: (1) data description, (2) vehicle classification analysis, (3) temporal factors analysis, (4) environmental factors analysis, (5) road factors analysis, and (6) speed analysis discussion. Speed data from the five WIM stations are combined and analysed for the vehicle classification, temporal, and road factor portions of the analysis while parts of the environmental factors analysis are analysed by individual station. The results are presented using a series of cumulative distribution graphs and times series graphs.

Data Description

Three types of data were utilized in this research: (1) WIM data, (2) lighting data, and (3) weather data. The origin and description of these data sets are described in this section.

WIM Data

Five weigh-in-motion devices operate year round at the locations of interest to this research. These devices classify vehicles according to the FHWA Scheme F in addition to collecting axle spacing and dynamic weight – and data from the devices can also provide accurate speed information based on the differences in detection time between successive sensors. Manitoba Highway Traffic Information System (MHTIS) is responsible for processing traffic volume data from these devices. MHTIS is a partnership between Manitoba Infrastructure and Transportation (MIT) and the University of Manitoba Transport Information Group (UMTIG). The primary use of the WIM devices in Manitoba is to produce traffic flow estimates for Manitoba highways. Although data from the devices can be used for speed information, this capability is uncommonly utilized.

Data for the complete 2010 year from the WIM stations (Stations 61, 63, 64, 65, and 80) is analysed in this research. Four of the five WIM devices are located on divided highways [two on Provincial Trunk Highway (PTH) 1, one on PTH 75, and one on PTH 100], and one is located on PTH 16, which is an undivided highway at the location of the station. Station 64 located on PTH 100 experiences different traffic characteristics than other stations due to its proximity to Winnipeg on the perimeter highway. This location sees a high number of local trips and experiences more congestion when compared to other site locations, particularly at peak hours. All station locations have a posted speed limit of 100 kilometres per hour.

The WIM devices collect speed and classification data year round, 24 hours per day. This results in nearly eight million vehicle records in 2010. The WIM data collection system rejects certain observations for a number of different reasons including tailgating, short headway distance, and lack of detection on one or more sensors. In some cases vehicles traveling at extreme speeds may not have a recorded speed and therefore cannot be classified. These cases may be entered as a class 0, as having a speed of 0 or there may be blank entries in specific fields. Records missing either speed or classification data were rejected for this research.

The WIM devices classify vehicles in accordance with the FHWA Classification Scheme F. Although the WIM devices classify vehicles in one of thirteen classes, a simpler classification scheme was developed for this research. The new classification scheme consists of five classes, allowing analysis of broad vehicle categories. The five classes consist of: (1) motorcycles, (2) passenger vehicles, (3) buses and single unit trucks, (4) single trailer combinations, and (5) multi-trailer combinations. Table 1 describes each class and indicates which FHWA Scheme F vehicles fall under each of the classes in the simpler classification scheme.

Table 1: Vehicle Classification Scheme Used in This Research

Class	FHWA Classes Included	General Description
1	1	Motorcycles
2	2,3	Passenger vehicles
3	4,5,6,7	Buses and small trucks
4	8,9,10	Single trailer combinations
5	11,12,13	Multi-trailer combinations

From this point forward reference to vehicle classifications will refer to the simple classification scheme developed for this research.

Lighting Data

Lighting condition data was required in this research to determine the times of dawn, day, dusk, and night at the station locations. The data was obtained from the National Research Council Canada (NRC) using their sunrise/sunset/sun angle calculator.

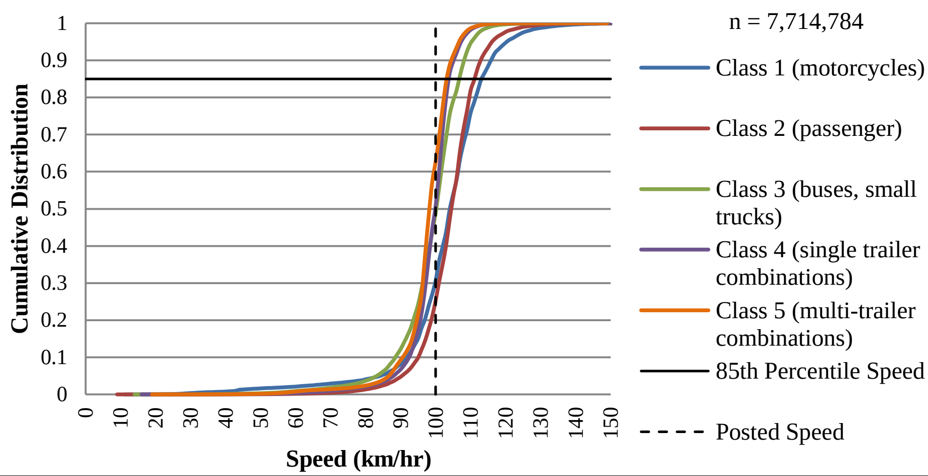
Weather Data

Manitoba does not operate weather stations at WIM device locations; for this reason weather stations collecting weather data located nearest to each station were utilized. Many weather stations collect hourly rain data, however, hourly or daily snow data is not as commonly collected. Weather stations collecting hourly rain data nearest to each WIM station were used for the rain condition portion of the analysis and additional weather stations collecting daily snow data at distances further away from the WIM devices were used for the snow condition portion. Weather conditions change frequently, particularly in terms of rain and snow intensities and therefore conditions at weather stations may not be entirely reflected at each WIM site.

Weather stations collecting hourly rain data were within 30 kilometres of WIM stations with the closest station being within one kilometre. Weather stations collecting daily snow data were within 50 kilometres of WIM stations with the closest station being within 18 kilometres.

Vehicle Classification Analysis

The five WIM stations analysed in this research were combined to determine the relationship between vehicle classification and operating speed. The vehicles were divided into five different classes described in Table 1. These classes generally consist of motorcycles (Class 1), passenger vehicles (Class 2), buses and small trucks (Class 3), single trailer combinations (Class 4), and multi-trailer combinations (Class 5). Figure 1 presents the cumulative distribution for each of the designated classes and supporting summary statistics.



	Class 1	Class 2	Class 3	Class 4	Class 5
Total Records	32,223	5,838,891	169,468	1,421,849	252,353
Mean Speed (km/hr)	104	105	99	99	98
15^{th} Percentile Speed (km/hr)	95	97	92	94	93
85^{th} Percentile Speed (km/hr)	113	111	107	104	103
Percent Above 90 km/hr	91	95	86	92	89
Percent Above Posted Speed (100 km/hr)	64	70	44	40	31
Percent Above 110 km/hr	21	15	4	1	1

Figure 1: Cumulative Speed Distribution by Vehicle Classification

Passenger vehicles and motorcycles were found to have the highest mean speeds of 105 and 104 kilometres per hour, respectively. Both of these vehicle categories showed mean speeds above the 100 kilometre per hour posted speed while trucks were found to have lower mean speeds ranging from 98 to 99 kilometres per hour. The 85^{th} percentile speed was found to be greater than the posted speed for all five vehicle classifications with motorcycles having the highest 85^{th} percentile speed and multi-trailer trucks having the lowest.

Nearly three quarters (70 percent) of all passenger vehicles were found to be exceeding the posted speed while 31 to 44 percent of trucks were found to be exceeding the posted speed. Fifteen percent of passenger vehicles and one to four percent of trucks were exceeding the posted speed by more than 10 kilometres per hour.

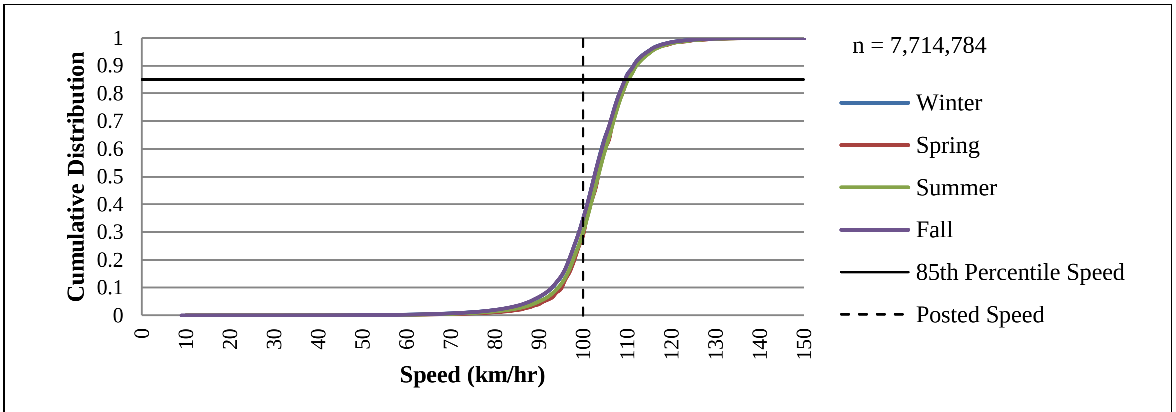
Temporal Factors Analysis

Four temporal factors influencing vehicle operating speed were analysed: (1) seasonal, (2) month of year, (3) day of week, and (4) time of day. Each of these characteristics is analysed independently and therefore does not include a breakdown by vehicle classification or type of roadway to avoid confounding factors.

Seasonal

The seasonal analysis of speed records included assigning speed records to one of four seasons with winter beginning on December 21st, spring on March 20th, summer on June 21st, and fall on September 22nd.

The cumulative distribution created for the seasonal analysis is presented in Figure 2. The mean speed was found to be similar throughout the year with 103 kilometres per hour in fall and winter, and 104 kilometres per hour in the spring and summer. The 85th percentile speeds range from 109 to 110 kilometres per hour and between 60 and 65 percent of vehicles were found to be exceeding the posted speed with the slightly higher percentages seen in the spring and summer.



	Winter	Spring	Summer	Fall
Total Records	1,508,981	2,016,389	2,399,193	1,790,211
Mean Speed (km/hr)	103	104	104	103
15th Percentile Speed (km/hr)	95	97	96	95
85th Percentile Speed (km/hr)	109	110	110	110
Percent Above 90 km/hr	93	95	94	92
Percent Above Posted Speed (100 km/hr)	60	64	65	60
Percent Above 110 km/hr	11	12	13	11

Figure 2: Cumulative Speed Distribution by Season

Month of Year

The month of year analysis consisted of dividing speed records into their respective months and presenting them in a time series graph seen in Figure 3. Mean speeds range from 102 to 104 kilometres per hour with slightly lower mean speeds typically occurring during winter months. The highest 85th percentile speed occurred in August and the lowest in January, November, and December. The percentage of vehicles traveling at speeds exceeding the posted speed ranged from 63 to 72 percent with a greater percentage of vehicles traveling above the posted speed in April, May, July, and August.

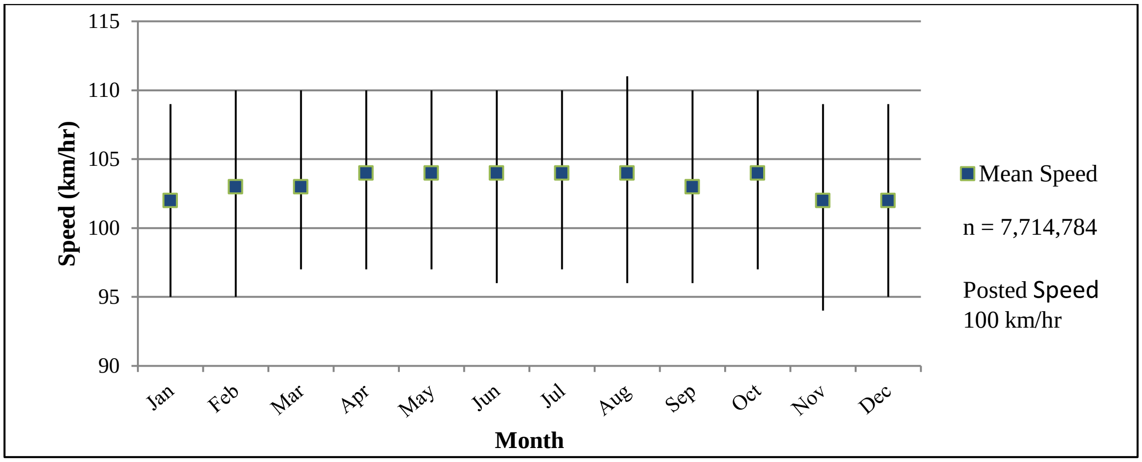


Figure 3: Speed by Month of Year (mean and 15th to 85th percentile range)

Day of Week

The day of week analysis consisted of dividing speed records into their respective day of week and presenting them in a time series graph seen in Figure 4. Mean speeds range from 103 to 104 kilometres per hour with lower speeds occurring during Monday through Thursday. The 85th percentile and 15th percentile speeds remained the same throughout the week at 110 and 96 kilometres per hour, respectively. The percentage of vehicles traveling at speeds exceeding the posted speed ranged from 66 to as high as 83 percent on Saturdays.

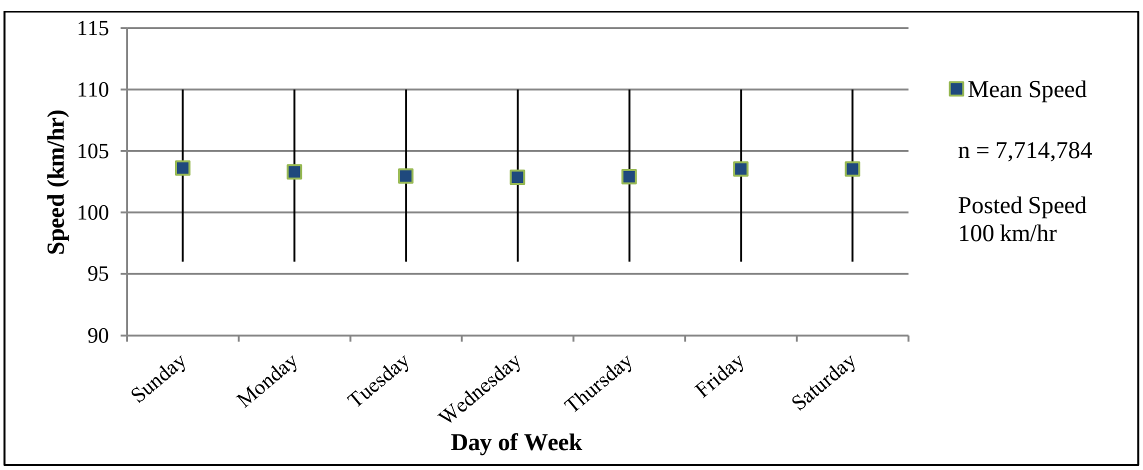


Figure 4: Speed by Day of Week (mean and 15th to 85th percentile range)

Time of Day

The time of day analysis consisted of assigning speed records to two-hour time intervals throughout the day. Mean speeds ranged from 101 to 104 kilometres per hour with hours between 02:00 and 06:00 having the lowest mean speeds and hours between 14:00 and 20:00 having the highest mean speeds. The 85th percentile speeds ranged from 107 to 110 kilometres per hour and the 15th percentile speed ranged from 93 to 97 kilometres per hour. The percentage of vehicles traveling above the posted speed ranged from 55 to 71 percent with the smallest percentages occurring during the early hours of the morning (0:00 to 0:600). The time series graph for vehicle operating speeds throughout different times of the day is presented in Figure 5.

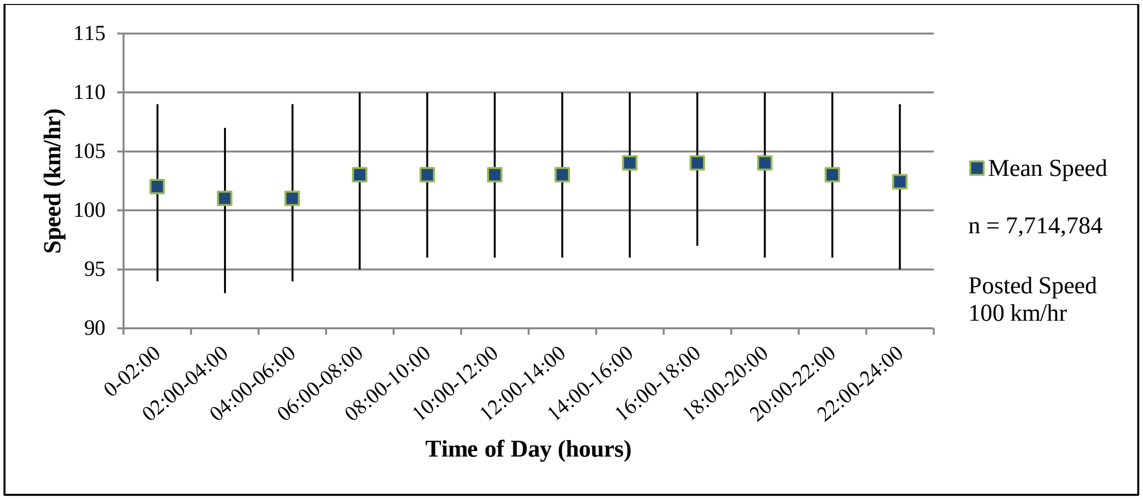


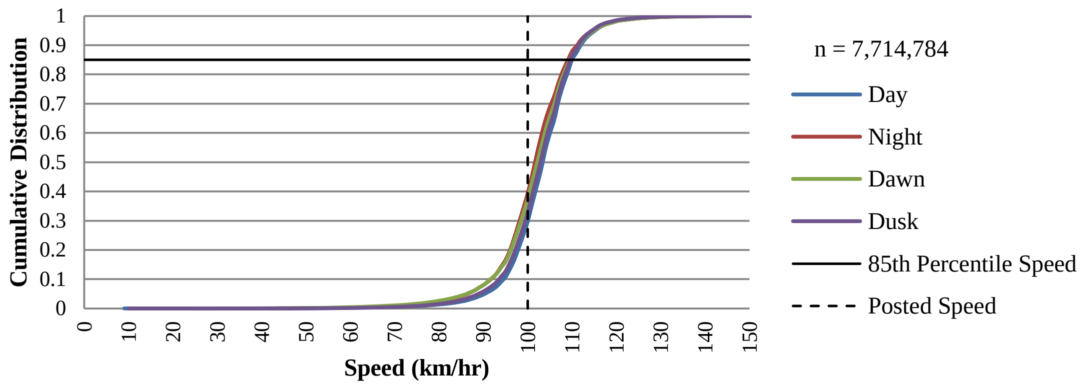
Figure 5: Speed by Time of Day (mean and 15th to 85th percentile range)

Environmental Factors Analysis

The environmental factors analysis component of this research consists of identifying speed patterns in terms of lighting factors and weather factors to determine their relationship with vehicle operating speed.

Lighting Factors

Four lighting factors were used in this analysis: (1) day, (2) night, (3) dawn, and (4) dusk. The mean speed was found to be highest during daylight conditions at 104 kilometres per hour with the lowest mean speeds occurring at night and dusk at 102 kilometres per hour. The 85th percentile speeds ranged from 109 to 110 kilometres per hour and between 54 and 64 percent of vehicles were found to be exceeding the posted speed. The lowest percentage of those travelling above the posted speed occurred during night and dusk (54 and 57 percent, respectively). The results of the lighting factors analysis are presented in Figure 6.



	Day	Night	Dusk	Dawn
Total Records	5,798,781	1,287,624	142,341	486,038
Mean Speed (km/hr)	104	102	102	103
15th Percentile Speed (km/hr)	96	94	94	96
85th Percentile Speed (km/hr)	110	109	110	110
Percent Above 90 km/hr	94	91	91	93
Percent Above Posted Speed (100 km/hr)	64	54	57	61
Percent Above 110 km/hr	13	10	11	11

Figure 6: Cumulative Speed Distribution by Lighting Condition

Weather Factors

The weather factors analysis includes two precipitation factors: (1) rain, and (2) snow. Additional weather factors with the potential to influence operating speed such as fog, pavement conditions, and wind conditions were not addressed due to lack of hourly data or poor proximity between WIM and weather stations.

An individual analysis is completed for each of the WIM stations for both rain and snow factors. Due to the varying distances between weather and WIM stations the weather factors experienced at the weather station may not be reflected at the location of the WIM device.

The rain precipitation analysis considers only those records with temperatures greater than 0°C and the rain categories used in this research are presented in Table 2.

Table 2: Rain Condition Categories

Rain Category	Precipitation Condition
Heavy Rain	≥8 millimetres per hour
Moderate Rain	≤7 and ≥3 millimetres per hour
Light Rain	≤2 millimetres per hour

The rain condition analysis resulted in different trends for each individual WIM station and corresponding weather data. This could be due to the distances between the stations as weather factors change quickly and frequently over time. It is difficult to determine the actual conditions at a WIM station based on the weather data and it is possible that the intensity of rain at a particular point and its impact on visibility may be a determining factor in a driver's speed selection as found in the literature. In general, differences in operating speeds during periods of rain and no rain were most pronounced at lower speeds (below the 15th percentile speed). The majority of the stations had small changes in operating speed when comparing heavy, moderate, light, and no rain conditions. Station 64 was an exception to this with greater differences in operating speeds for the different conditions; this may be due to the more urban like location of this station on Winnipeg's perimeter highway.

The snow condition analysis consisted of matching WIM stations to weather stations collecting daily snow data. The ten days with the greatest amount of snowfall in 2010 for each weather station are compared to ten winter days with no snowfall that are at least three days away from major snowfall events. This analysis was done on a daily basis rather than an hourly basis for two reasons: (1) lack of hourly snow data; and (2) increased distances between WIM and weather stations used for snow data. Since the WIM devices are located between 18 and 46 kilometres from weather stations used for snow data, hourly conditions may not be reflected at WIM devices and therefore daily snowfall values are used instead. The ten days used in each analysis have daily snowfall ranges between 1.9 and 20 centimetres.

The five WIM stations experienced similar results in the snow data analysis. The mean speeds were found to be between three and six kilometres per hour lower during days with snow than days with no snow. 85th percentile speeds were also found to be lower on days with snow than days with no snow by two to three kilometres per hour. Figures 7 to 11 present the results of this analysis. In all cases the greatest differences in speeds were seen at lower speeds; this could indicate that the more cautious drivers take the weather conditions into consideration when selecting their speed. For instance during periods of snow, between 30 and 47 percent of drivers were found to be exceeding the posted speed while during periods without snow 47 to 64 percent of drivers were exceeding the posted speed.

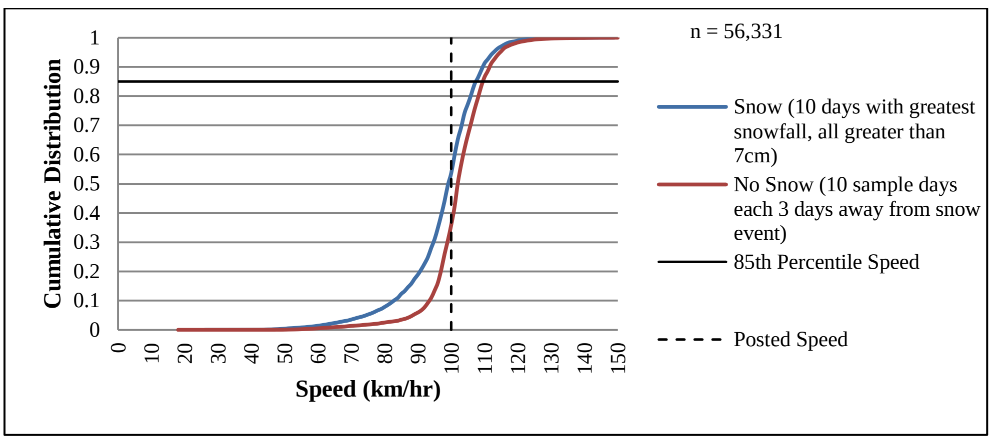


Figure 7: Station 61 Cumulative Speed Distribution by Snow Presence

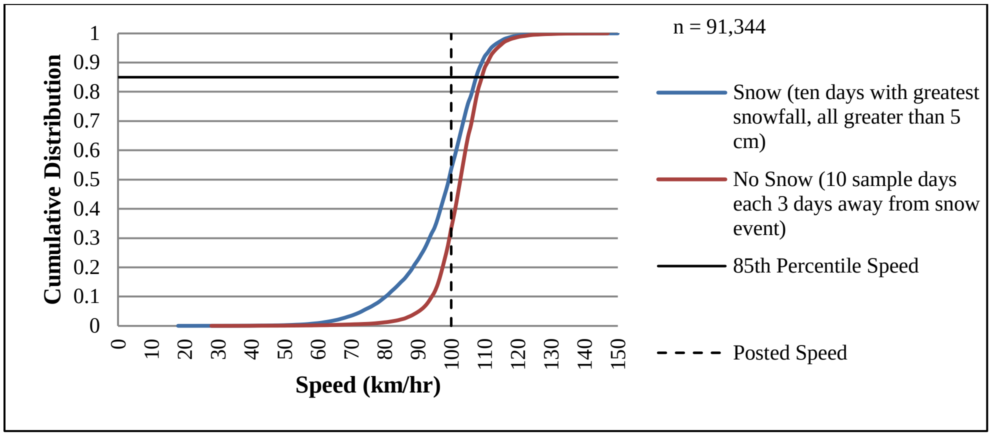


Figure 8: Station 63 Cumulative Speed Distribution by Snow Presence

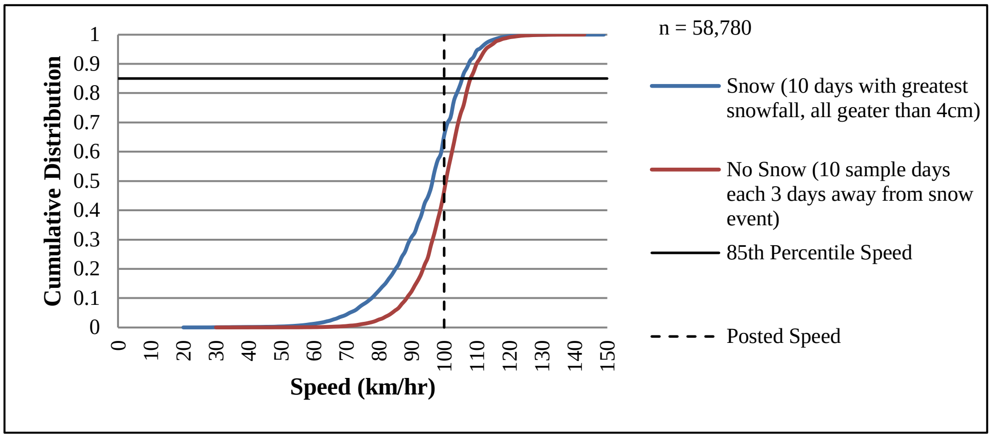


Figure 9: Station 64 Cumulative Speed Distribution by Snow Presence

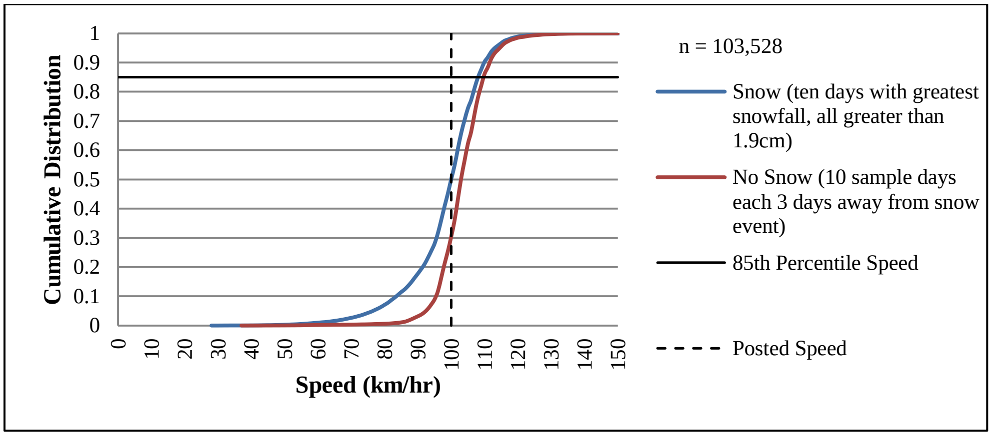


Figure 10: Station 65 Cumulative Speed Distribution by Snow Presence

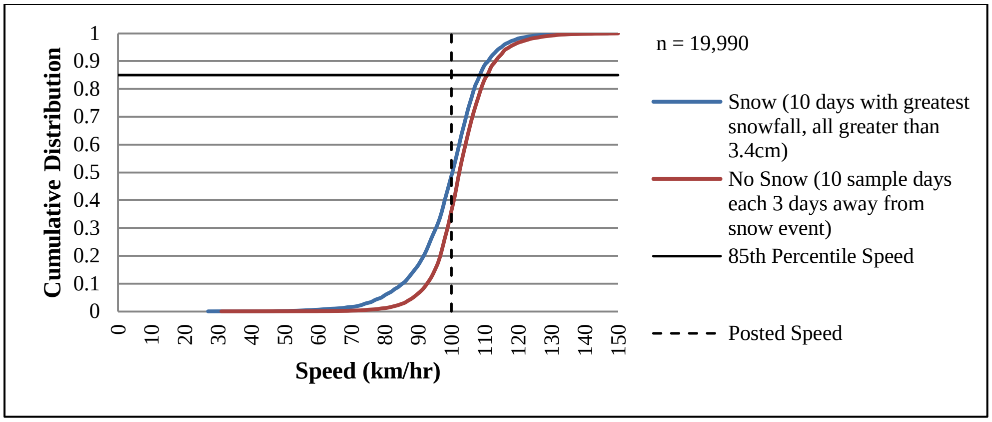


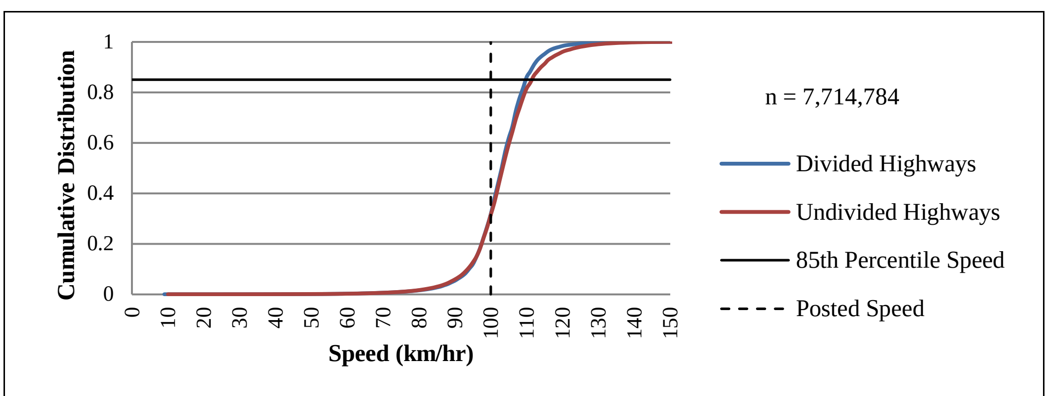
Figure 11: Station 80 Cumulative Speed Distribution by Snow Presence

Road Factors Analysis

Two comparisons were made based on road type in this analysis: (1) between divided and undivided highways, and (2) between urban and rural highways. Four of the five stations are located on divided highways (Stations 61, 63, 64, and 65) and four of the five stations are located in rural regions (Stations 61, 63, 65, and 80).

Divided and Undivided Highways

The divided highways (four lanes) exhibited a lower mean speed of 103 kilometres per hour versus 104 kilometres per hour for the undivided highway (two lanes). This may be due to the lower traffic volume seen at Station 80 with an Annual Average Daily Traffic (AADT) of 1,630 while the divided highways experience AADTs ranging from 5,170 to 8,970. Differences in speeds are greatest at higher speeds (above the 85th percentile speed). The results of the analysis are presented in Figure 12.

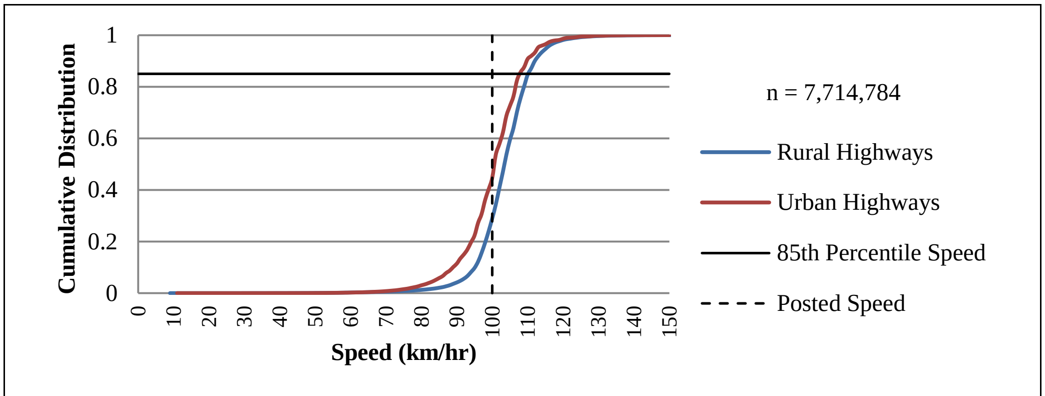


	Divided Highways	Undivided Highways
Total Records	7,167,410	547,374
Mean Speed (km/hr)	103	104
15th Percentile Speed (km/hr)	96	79
85th Percentile Speed (km/hr)	110	111
Percent Above 90 km/hr	94	93
Percent Above Posted Speed (100 km/hr)	62	64
Percent Above 110 km/hr	12	16

Figure 12: Cumulative Speed Distribution by Highway Type: Divided and Undivided

Urban and Rural Highways

The only station operating in an urban area is located on Winnipeg's perimeter highway. This portion of highway sees a high proportion of daily trips to and from places of work, school or other daily trips. The AADT at this urban location is the highest of the five WIM stations with 8,970 and additionally has one of the highest Annual Average Daily Truck Traffic (AADTT) of 1,400. Figure 13 presents the cumulative speed distribution for the rural and urban highways.



	Rural Highways	Urban Highways
Total Records	6,373,240	1,341,544
Mean Speed (km/hr)	104	100
15th Percentile Speed (km/hr)	97	92
85th Percentile Speed (km/hr)	110	108
Percent Above 90 km/hr	95	87
Percent Above Posted Speed (100 km/hr)	66	46
Percent Above 110 km/hr	13	8

Figure 13: Cumulative Speed Distribution by Highway Type: Rural and Urban

The mean speed was found to be four kilometres per hour greater for rural highways than urban highways. From Figure 13 it can be seen that the operating speeds of the two highways grow closer at higher speeds and have greater differences at lower speeds. The 85th percentile speeds are similar with 110 kilometres per hour and 108 kilometres per hour for rural and urban highways, respectively. Rural highways exhibited a greater percentage of vehicles exceeding the posted speed (66 percent) when compared to the urban highway location (46 percent).

Speed Analysis Discussion

Each of the speed distribution curves reveals speed behaviour differences as influencing factors vary, and the extent of differences depends on the general region of the cumulative distribution curve. The following analysis examines speed behaviour differences in response to influencing factors in three general regions of the cumulative distribution curve: the slower region, the middle region, and the faster region.

For each region of the curve, speed behaviour difference is measured in two ways: the difference in proportions of vehicles exceeding a threshold speed (vertical distance between two curves) and the difference in speed value at a reference distribution parameter (horizontal distance between two curves). The threshold speeds to measure proportion differences are the posted speed, and 10 kilometres per hour above and below the posted speed. The reference distribution parameters to measure change in speed value are the mean, 15^{th}, and 85^{th} percentile speeds. Table 3 shows a summary of speed behaviour differences as influencing factors vary.

Table 3: Speed Behaviour Differences as Influencing Factors Vary, Disaggregated According to Region on Speed Distribution Curve

Factors Compared	Slower Region of Curve		Middle Region of Curve		Faster Region of Curve	
	$\Delta p_{posted-10km/hr}$	ΔV_{15} km/hr	Δp_{posted}	$\Delta\bar{V}$ km/hr	$\Delta p_{posted+10km/hr}$	ΔV_{85} km/hr
1. Passenger Vehicles 2. Single Trailer Combinations	-0.01	-4	-0.14	-6	-0.20	-7
1. Undivided 2. Divided	0.01	17	-0.02	-1	-0.04	-1
1. Rural 2. Urban	-0.08	-5	-0.20	-4	-0.05	-2
1. Winter 2. Summer	-0.02	-1	-0.05	-1	-0.02	-1
1. Day 2. Night	-0.03	-2	-0.10	-2	-0.03	-1
1. No Rain 2. Heavy Rain	-0.06	-3	-0.09	-1	-0.02	-1
1. 10 Worst Snow Days 2. No Snow	-0.15	-7	-0.17	-5	-0.04	-2

Notes: Δp_n is difference in proportion of vehicles travelling above speed n; ΔV_{15} is change in the 15^{th} percentile speed, $\Delta\bar{V}$ is change in mean speed; ΔV_{85} is change in 85^{th} percentile speed; negative values indicate a drop from the first factor to the second. Differences considered moderate and large are highlighted in light and dark grey respectively.

The following terminology interprets the size of speed behaviour differences:

- small: proportion change up to 0.049 or speed change up to 4.9 km/hr;
- moderate: proportion change 0.050 to 0.149 or speed change 5.0 km/hr to 14.9 km/hr; and,
- large: proportion change 0.150 and higher or speed change 15.0 km/hr and higher.

Table 3 reveals the following points about speed behaviour differences:

- In general, in the faster region of the curves, there is a small difference in speed behaviour as influencing factors vary. This is especially evident in the rain and snow results. For example, during heavy rain, the reduction in proportion of drivers travelling more than 10 kilometres per hour over the speed limit is 0.02, and the reduction in the 85^{th} percentile speed is one kilometre per hour. This may mean that the same drivers who choose to travel at high speeds relative to other drivers also choose to not adjust their speeds according to season, lighting, or environmental factors.

- In general, in the slower and middle regions of the curves, during rain and snow conditions, there is a moderate to large reduction in the drivers choosing to travel above the threshold speeds. For example, on the snow days, the proportions of drivers travelling above 90 and 100 kilometres per hour drop by 0.15 and 0.17, respectively, as compared to no snow days. On the worst snow days, 15th percentile speed and mean speed drop by seven and five kilometres per hour, respectively. There are also moderate reductions in the proportions of drivers travelling above the posted speed during winter months overall and during night time lighting conditions (reductions of 0.05 and 0.10, respectively). This may mean that the drivers that do not choose to travel at high speeds relative to other drivers (the slower and middle regions of the curve) also choose to adjust their speeds according to season, lighting, and environmental factors.

- In contrast to the general results, when cars and trucks are compared, large differences are observed in the faster region of the curve. The proportion of drivers travelling more than 10 kilometres per hour over the posted speed is lower for trucks than it is for cars by a large amount (0.20), while the proportion exceeding the posted speed is lower for trucks than cars by a moderate amount (0.14). This may reflect different driver characteristics, corporate policies of truck carriers, or the influence of mandatory speed limiting equipment for trucks in neighbouring jurisdictions.

- On the undivided highway, drivers travel faster than on divided highways by a small amount in the middle and faster regions of the curve. This may be a result of a perception of lower enforcement levels on the lower volume undivided highways. In the slower region of the curve, the opposite is true: the 15th percentile speed is lower on the undivided highway than on divided highways by a large amount (17 kilometres per hour). This may be a result of a higher proportion of unusually slow trips on the undivided highways – perhaps for agricultural purposes. For undivided highways, higher speeds among faster drivers and lower speeds among slower drivers combine to create a higher speed variance, which the literature review found was negatively associated with safety.

CONCLUSION

The literature review revealed six key factors with the potential to influence operating speed: (1) road engineering, (2) vehicle classification, (3) temporal factors, (4) weather factors, (5) driver attitude and behaviour, and (6) regulatory and enforcement environment.

The speed data analysis comprised four components: (1) vehicle classification (motorcycles, passenger vehicles, small trucks and buses, single trailer combinations, and multi-trailer combinations), (2) temporal factors (seasonal, monthly, day of week, and time of day), (3) environmental factors (lighting and weather factors), and (4) road factors (divided and undivided highways, and urban and rural highways). Key findings from the analysis include:

- Motorcycles and passenger vehicles were found to have the highest operating speeds with mean speeds of 104 and 105 kilometres per hour, respectively.
- Buses and small trucks, single trailer combinations, and multi-trailer combinations had the lowest mean speeds of 98 to 99 kilometres per hour.

- The monthly analysis exhibited mean speeds ranging from 102 to 104 kilometres per hour with lower speeds typically occurring during the winter months.
- The day of week analysis had mean speeds ranging from 103 to 104 kilometres per hour with the higher mean speeds occurring on Fridays, Saturdays, and Sundays.
- Hours between 02:00 and 06:00 had the lowest mean speeds and hours between 14:00 and 20:00 had the highest mean speeds with all mean speeds ranging between 101 and 104 kilometres per hour.
- Daylight conditions exhibited a higher mean speed (104 kilometres per hour) when compared to other lighting conditions and the lowest mean speeds occurred during night and dusk (102 kilometres per hour).
- Days with snow had lower mean speeds than on days with no snow by around three to six kilometres per hour. The greatest differences in speed occurred at lower speeds (below the 15^{th} percentile speed).
- The urban location was found to have a lower mean speed when compared to the rural locations by four kilometres per hour. Differences in operating speeds were found to be most pronounced at lower speeds (below the 15^{th} percentile speed).

The analysis of speed data reveals speed behaviour differences as influencing factors (e.g., precipitation, lighting, vehicle type) vary. The analysis also reveals that the *extent* of speed behaviour differences as the influencing factors vary is not constant throughout the speed distribution curve: the differences are generally greater in the lower speed regions of the curve, except when the influencing factor is vehicle type, where the differences are greater in the higher speed region of the curve.

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