Weather and Surface Transportation: Exploring Operational Impacts

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Abstract

Inclement weather is a serious concern for mobility. This problem is especially true for the movement of goods as the uncertainty related to weather events poses significant cost to the freight industry. This paper begins with an exploration of the potential areas of concern related to weather impacts on rail and trucking operations. For the trucking sector, determining the time delays and costs of these impacts has proven difficult. For example, the Highway Capacity Manual (2000) provides basic measurements for calculating weather related delay for road systems. However, a significant number of empirical studies, both before and after the publication of the Highway Capacity Manual (2000) provide further insights that may improve our understanding. In this paper, we present a meta-analysis of these studies across

North America to extract factors of travel delay due to weather conditions. The data is then contrasted with a detailed daily sample from several traffic and weather stations in British Columbia. The results present factors of delay for rain and snow that are useful for modeling travel times and determining the impact and cost of delay due to inclement weather. The results aid our understanding of the effects of weather on surface freight systems and form the basis for a larger study into the impacts of weather on surface freight systems in a changing global climate.

Introduction

Canada and its society is particularly connected to the variety of weather that is a pervasive influence across this Nation. This is true in transportation as well, where the weather has a multifaceted impact. In terms of causing system delays, it has been estimated that millions of hours of highway traffic delay (46 million in 1999 across U.S. highway network) are the exclusive result of weather (Han et al. 2003). Additionally, winter poses heavy costs for Canada's transportation sector (Jackson 1992), with decreased fuel efficiency being important beyond the costs of delays (Ash and Gardner 1997).

Addressing the issue of a changing climate, it has been argued that global warming will lead to milder winters, which one could argue is a good thing. However, it has been suggested that we may encounter more frequent severe weather events, including winter storms which could be a bad thing (Francis and Hengeveld, 1998).

Regardless of the viewpoint taken, it is critical to realize that fundamental to exploring the future climate question is a basic understanding of how the transport system currently contends with weather

In general, our understanding of how weather and climate impacts transportation is not based on substantial research effort (Andrey and Mills, 2003) . We know anecdotally that weather matters a great deal to surface transportation but our detailed, quantified understanding in this area is lacking despite recent efforts. The goal in this paper is to address this gap. First, a specific focus on weather related delays on highways systems is drawn out from a broader discussion of weather and surface transportation. Second, a critical review of existing empirical work is provided. Finally, a Canadian based example of quantifying weather delay is reviewed with recommendations for future work provided as part of the discussion.

Weather and Surface Transport

The transportation system in Canada deals with the spectrum of weather and climate on an ongoing basis. This spectrum ranges from acute impacts (extreme weather conditions or events) to chronic/cumulative or long term impacts (more routine conditions or events) (Andrey and Mills, 2003). Prentice (2003) follows a similar convention in recognizing that climate is a source of “chronic” and weather “temporary” transportation system bottlenecks. In terms of system impacts, it is useful to think along the lines of infrastructure, mobility (operations) and safety aspects.

Long-term climate trends, like freeze thaw cycles, temperature extremes and precipitation have a major impact on road infrastructure, winter road maintenance, and influence insurance costs. In the U.S., for example, winter related road damage has been estimated at $5 billion per annum (Nelson and Persaud (2002). Winter road maintenance is an important budget challenge for many Canadian jurisdictions. Further, decisions around long term investment in transportation infrastructure are also influenced by long term weather and climate trends. Promoters of one of the "River of Trade Corridor Coalition" suggest their corridor it is a better bet for investment in this age of modern global logistics because it passes through areas with a more moderate and reliable climate – unlike the U.S. Midwest. (Blaydes, 2007)

Operationally, major winter storm events may present major delays for shipments on both the road and rail systems, and increase the risk for accidents. Even average to moderate weather events are estimated to result in up to 12% travel time delays, which can translate into substantial economic impacts (Nelson and Persaud 2002). The rail system is less prone to extreme cold weather because of technological innovations (continuous weld rail) but it still presents major operational challenges. The mountain areas are a persistent challenge as well, historically being prone to closures as a result of avalanche, rock slide, or mud slide activity as a result of cumulative poor weather.

Weather events (along with construction and accidents) are the major source of non-recurrent highway delays (the part of travel delay not related to volume/capacity issues). These impacts on goods movement are very important in this age of just-in-time (JIT) production and quick-response (QR) retailing. It has been argued that firms are just as sensitive to time and reliability of delivery as they are to rates when making choices on how to ship goods (Coyle et al., 2003). Many major companies like UPS have their own meteorological divisions responsible for tracking weather events, issuing alerts, and triggering contingency plans. Even with a 30% risk of an event, they issue an alert and plan for contingency (Richardson 2003). Similarly, one of Canada's major railways engages in a considerable winter contingency planning effort.

From a safety standpoint Koiser and Summerfield (2001) argue that weather's role in heavy truck accident causation may be greater than previously suggested and in their study, concluded that 41% of truck accidents were related to poor weather road conditions and high winds compared to 32% for passenger vehicles.

This brief discussion has highlighted a number of ways in which weather influences surface transportation in terms of short and long term impacts. It is by no means comprehensive and does not delve into other modal considerations. Moving forward, we have decided to focus on highway traffic delay because of its relevance to transportation writ large.

Weather Delay Research

Table 1 summarizes recent empirical work which

Table 1: Comparing Studies: Speed Reduction at Free-Flow Due to Inclement Weather

Authors	Year	Facility	Speed Reduction*	Categories	Elements **
Lamm et al	1990	Two-lane rural highway	minimal reduction under wet conditions	Wet or Dry	6
Ibrahim and Hall	1994	Freeway	LR = 13 km/h; HR = 5-21 km/h	Highest and lowest precipitation events by range	1,2
Brilon and Ponziet	1996	Freeway	WH (2 lane) = 9.5 km/h; WH (3 lane) = 12 km/h	Wet or Dry	5, 6
Liang et al	1998	Interstate Highway	V ~ logarithmic relationship; N = 1.6 km/h; T<0 = 1.6 to 3.2 km/h; WS ~ 1.1 km/h for each km/h that wind speed is above 40 km/h	16 problem days where visibility was significantly reduced	2,3,4,5,6,7
HCM 2000	2000	Freeway	LR = 2 km/h; HR = 5-7 km/h; LS = 1 km/h; HS = 37-42 km/h	Rain (Light, Heavy), Snow (Light, Heavy)	1,2
Kyte et al	2000	Freeway	LR & LS = 14.1 - 16.5 km/h; HR = 31.6 km/h; HS = 38 km/h; WS(High) = 9 km/h	Wind Speed><48 km/h; Precipitation (4); Roadway (dry, wet, snow/ice)	1,2,3,4,6
Kyte et al	2001	Freeway	WH = 9.5 km/h, SH = 16.4 km/h; WS>24 km/h = 11.7 km/h; V<0.28 km/h ~ 0.77 km/h for each 0.01 km loss of visibility	Wind Speed ><24 km/h, Snow-cover (Y/N); Wet Surface (Y/N); Visibility (km)	1,2,3,4,6
Knapp	2001	Interstate Highway	V>0.4 km = 6.3 km/h, SH = 11.6 km/h	Visibility <1/4 mile (Y/N), Snow-Cover (Y/N)	2,8
Chin et al (see also Han et al)	2002	Freeway	LR = 10 km/h; HR = 16 km/h; LS = 10 km/h; HS = 50 km/h; Fog has operating speed of 50 km/h	Rain (Light, Heavy), Snow (Light, Heavy), Heavy Fog (Y/N)	1,2,3
Stern et al.	2003	Metro Network	Regression Analysis; Travel time = Base Travel Time + B1(Precipitation) + B2(Wind) + B3(Wind) + B4(Pavement Condition)	Precipitation (4); Wind ><30mph; Visibility < 1/4 mile (Y/N); Pavement Condition (4)	1,2,4,6,8
Maze et al. (see also Agarwal et al 2005)	2005	Urban Freeway	LR = 1-6%; HR= 4-7%; LS = 3-10%; HS = 11-15%; -20<T>0 = 1-1.5%; T<-20 = 0-3.6%, 16 km/h<WS>32 km/h = 1%; WS>32 km/h = 1-1.5%; V>0.25 km = 6-7%; V<0.25 km = 11%	Rain (3), Snow (4), Temperature (4), Visibility (4)	1,2,4,7,8

* LR = Light Rain; HR = Heavy Rain; LS = Light Snow HS = Heavy Snow; WH = Wet Hwy;

SH = SnowCovering Hwy; V = Visibility; N = Night; T = Temp; WS = Wind Speed

** 1 = Rain; 2 = Snow; 3 = Fog; 4 = Wind; 5 = Daylight Conditions; 6 = Highway condition (wet, snow or icepack) 7 = Temperature, 8 = visibility addresses the complex relationship between highway travel speeds and weather conditions. The majority of studies recognize that understanding highway speeds is more than just a function of speeds, but address volume and capacity impacts as well. The table is organized by study year, and includes a major column indicating the speed reduction (delay) in Km/h associated with a variety of weather conditions, as well as all weather conditions considered in the study (final column).

The majority of studies conclude that precipitation, in particular snow, has the greatest impact on reducing highway speeds. For example, the Highway Capacity Manual (HCM, 2000) suggests heavy snow (typically greater than 15 cm in a 24 hour period) can reduce free flow highway speeds by 37 to 42 km/h. This is a combination of reduced visibility, loss of traction, and a reduction in capacity. While other visibility influences such as fog, and other weather variables such as wind are also influences, there are major challenges in terms of acquiring data on them. Environment Canada, for example, may indicate a daily wind speed gust, or it may provide an indication of visibility, but these are subjective measurements and the temporal and spatial detail is lacking. This represents one of the fundamental challenges in understanding weather influences – the dynamic nature and need for a fine scale of data.

The studies in Table 1 vary in their temporal and spatial scope, which is of critical importance to the transferability of the results. For example, the lone Canadian example by Ibrahim and Hall (1994) focuses on a few sections of the QEW near Hamilton, does not deal with congested time periods, and only explored the impacts of a handful of weather events. In contrast, the effort by Han et al., (2003) examined the entire U.S. highway system and the effort by Maze et al. (2005) is based on detailed 10 minute sampling of weather and travel speed conditions over a 4 year period. Clearly, the results from the latter study would provide a much more reliable understanding of weather and highway speeds given this detail. However, the authors explored statistical relationships, but stopped short of building any regression models relating measured weather conditions to speed. Kyte et al (2000, 2001) provide a detailed exploration on Iowa's rural highways and their effort is noteworthy for its emphasis on modeling the relationships. For a given intensity of precipitation, a parameter is estimated which quantifies the direct influence on highway speed. This detail is valuable because it would allow the estimation of travel speeds in areas based on anticipated weather events.

One of the major challenges in exploring the research results summarized in Table 1 is establishing the intensity of weather events. Often, subjective terms like "light" and "heavy" are utilized, but not well defined in terms of amounts (how much rain is "heavy") and time frame (per hour or day). 15 cm of snow in a given day will differ in its influence if it falls over an 18 hour period or a 3 hour period. Similarly, the cumulative impact of snow events over a series of days is difficult to capture. Some studies (Maze et al., 2005) had the advantage of a finer temporal scale of measurement and were able to report their weather data in “per hour” amounts. This is critical in the context of this paper, since in the Canadian context, the majority of weather stations (Environment Canada) report daily figures for precipitation. The challenge is if we can establish the same kind of relationships between weather and speeds utilizing daily data as others have done with hourly data.

Canadian Example: The Case of B.C.

The Ministry of Transportation for British Colombia provides access to a rich database on highway use and volumes via its website. The brief example provided in Figures 1 and 2 is drawn from 2005 data for a recording station on Highway 1 west of Abbotsford BC.. The variable of interest is “average daily speed” which represents an average of recorded speeds from all 4 lanes throughout a given day. As such, it obviously masks much of the daily rhythm and minute by minute changes in speeds. However, it serves as a legitimate compliment to the weather data from a nearby Environment Canada weather station, which is reported in terms of daily totals and minimum/maximums. The advantages of the breath of coverage (locations throughout the Province) and historical basis (days for a number years) in this case are appealing.

The 2005 weather and speed data are reduced down to days which had measurable precipitation amounts – rain greater than 5 mm and all snow events. The simple regression results are displayed as equations on the figures and it should be noted that in each case, the

Fig. 1 Daily Rain and Average Highway Speed

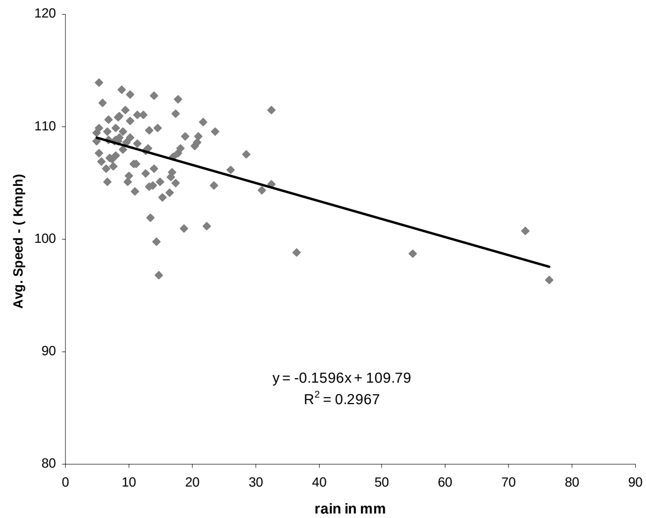
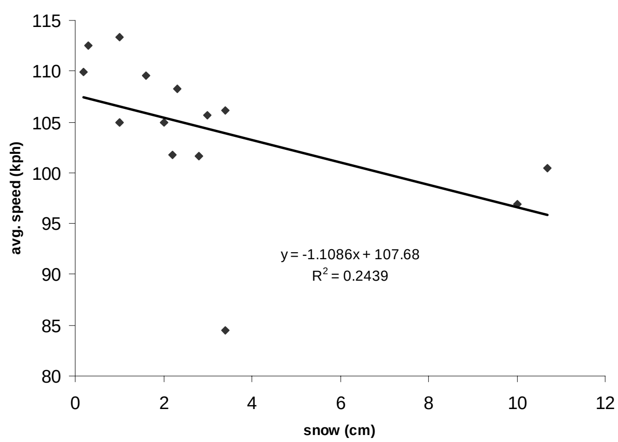


Fig. 2 Daily Snow and Average Highway Speed



parameters relating rain/snow to speed were significant. Clearly, the reported R^2 values (0.29 for rain, 0.24 for snow) suggest that there is a good deal of variability in average daily highway speeds that is not captured in this relationship. This is not surprising given the range of factors which determine average highway speeds at any given point in time (Ash and Conquist, 2006).

The parameter values from these models can be used to predict average speeds under various rain and snow levels. For example, a typical average daily speed is 109 kmph, and this speed is reduced to approximately 90.7 kmph with 15 cm of snow. This represents a reduction of 15.6% which is in agreement with the findings of Maze et al. (2005), a study which employs more detailed intensity data. Similarly, the reductions in average highway speed associated with rainfall based on Figure 1 correspond to the lower percentages as reported in the HCM results (see Table 1). Based on the model in Figure 1, a 25mm rain day would result in a 3.7 kmph drop in average speed or roughly 3.5 %. This falls roughly between the "light" and "heavy" rain reductions in the HCM and matches with percentage reductions reported by Maze et al., for their moderate rain intensity category (0.01 to 0.25 inches of rain per hour). Rain is associated with less speed reduction in general, and it can be further argued that given the high frequency of rain events throughout the year in this location, that drivers are more accustomed to these conditions and hence we would expect to see less delay (speed reduction) as a result. This argument has implications for the transferability of these relationships to other jurisdictions.

Discussion

The results presented here provide support for the value of utilizing publicly available low cost data sources to better understand the relationship between weather events (rain and snow) and highway travel speed reductions (delays). However, this support is currently very limited for a number of reasons. The use of an average speed, especially on a 4 lane highway is questionable, for among other reasons because it masks the differences between lanes. This is relevant given our interest in surface freight and an argument that trucks would tend to make up a larger percentage of inside lane traffic. Indeed, exploring the detailed lane speeds available, it is clear that there is greater variability in outside lane speeds.

More critical though is the limitation related to our brief exploration. Beyond the results presented here, we have examined a range of sites within BC, to better capture the variability in highway type and activity as well as weather regimes (mountains vs lower mainland for example). Even with this larger sample, our ability to draw more concrete conclusions runs up against the challenge of teasing out relationships that are dynamic and very time specific with aggregate data sources. One promising avenue of further work would involve turning to non traditional sources of weather data, such as those data collected by BC MOT at various weather stations located along their highway network. These sources often provide finer temporal resolution (minutes) and could better represent the intensity of weather events. They could be used in conjunction with the more detailed travel speed data for selected locations. They could also be employed in conjunction with truck specific travel speed data which is now obtainable through the commercial firms providing vehicle tracking for truck fleets (see Ash and Conquist, 2006).

Conclusions

This paper has provided a brief examination of a complex topic – namely how weather influences surface freight operations. The empirical results suggest that even the use of readily available daily weather and average highway speed data can be used to better understand this relationship. This has important implications for examining this issue in the Canadian context on a number of fronts. The importance of time reliability in modern logistics provides an impetus to better understand the uncertainty and delay related to weather events. Looking longer term, the location decisions of firms and infrastructure investments by our governments will be impacted by a changing climate. Getting a better handle on how current conditions play a role may contribute to more effective decision making for the future.

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