FOG: IMPACT ON ROAD TRANSPORTATION AND MITIGATION OPTIONS

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ABSTRACT

Highway accidents involving fog are often chain-reaction collisions involving dozens, sometimes hundreds, of vehicles, frequently accompanied by high casualty figures. As a consequence, media attention and the need for response measures are often high.

We will examine fog accidents in Canada, and elsewhere, over the past decade, and investigate mitigation options within the Canadian Architecture for Intelligent Transportation Systems.

Introduction

In considering severe and high-impact meteorological events in Canada, attention can easily become focussed on the more dramatic. Tornadoes, hurricanes and "east coast storms", for example, are readily recognized by the general public and the meteorological community alike for their societal consequences. Fog, on the other hand, does not lend itself as readily to this categorization. Yet, both in cost and casualties, fog has consistently impacted society, and in particular the transportation sector - sometimes with devastating consequences.

On Canada's highways, more than fifty fatal collisions occur each year in dense fog/smog/mist conditions (Transport Canada, 2001). A percentage of these events result from multi-vehicle pile-ups on high-speed highways. The well-known 145-vehicle Windsor, Ontario crash on September 3, 1999 resulted in eight deaths and over 150 injuries. More recently, a chain-reaction crash involving 49 vehicles near Chambly, Quebec on September 26, 2002 led to a single fatality and 17 injuries. Two days later, a similar incident near Winnipeg involved eleven vehicles and one death. Another pile-up outside Barrie, Ontario on March 17, 2003 involved over 200 vehicles and resulted in two dozen injuries. In all cases, on-site officials cited fog as the cause or major contributing factor.

The meteorological community has made significant strides in identifying and predicting severe and high-impact meteorological events. Tornadoes and hurricanes, for example, are more readily identified through recent technological advances in Doppler Radar and satellite imagery. Fog, by its nature, is a small-scale, often short-lived phenomenon that does not lend itself as easily to identification and prediction.

Analysis

In recent years, increases in highway infrastructure have not kept pace with increases in vehicle registrations, while truck traffic has risen in response to enhanced Canada-US trade (MacIver, 2002). These results have lead to over-crowding and highway congestion, which, when coupled with continued high-speed traffic during peak periods, has lead to an increased potential for multiple-vehicle pileups.

It is clear that weather conditions play a significant role in highway collisions. Accident rates have been shown to increase from 40 to 300 percent when precipitation occurs (Andrey, 1998). Dense fog conditions can be particularly dangerous. Scientific studies (Snowden, 1998) have shown that drivers tend to underestimate speed in dense fog and low visibility conditions, perhaps in response to a lack of identifiable markers. Drivers are often moving faster than their target speed, which frequently is faster than the recommended speed.

As well, dense fog frequently forms late at night, when weather conditions in valleys, over rivers and lakes and other low-lying areas are ideally suited to condensation and fog formation. In the early morning hours, during rush-hour traffic, visibilities can be very poor and highly variable. The Windsor, Chambly, Winnipeg and Barrie accidents all occurred in the early morning hours.

Since 1988, the number of fatal collisions in "fog/smog/mist" conditions range from a low of 35 in 1997 to 80 in 1992.   In absolute terms, the number of fatal collisions associated with fog, smog and mist has been increasing since 1993 (Figure 1).   Meanwhile, the total number of fatal accidents has steadily declined since 1990 (Transport Canada, 2001).

The reduction in total accidents is a consequence of a wide range of factors, including safer cars and trucks, increased seat belt use, graduated licenses in many provinces and more severe penalties for impaired driving.   Meanwhile, the frequency of fog occurrence has declined (Muraca, 2001).   Since the national fatal accident rate due to all causes and the frequency of occurrence of fog are both declining, even a slight increase in fatal accidents associated with fog is a significant increase in relative terms.

Trends in transportation and other societal factors will likely continue to aggravate this situation. Volumes of traffic on our roads may continue to rise while suspended particulate matter in the atmosphere provides an abundance of condensation nuclei for fog formation.
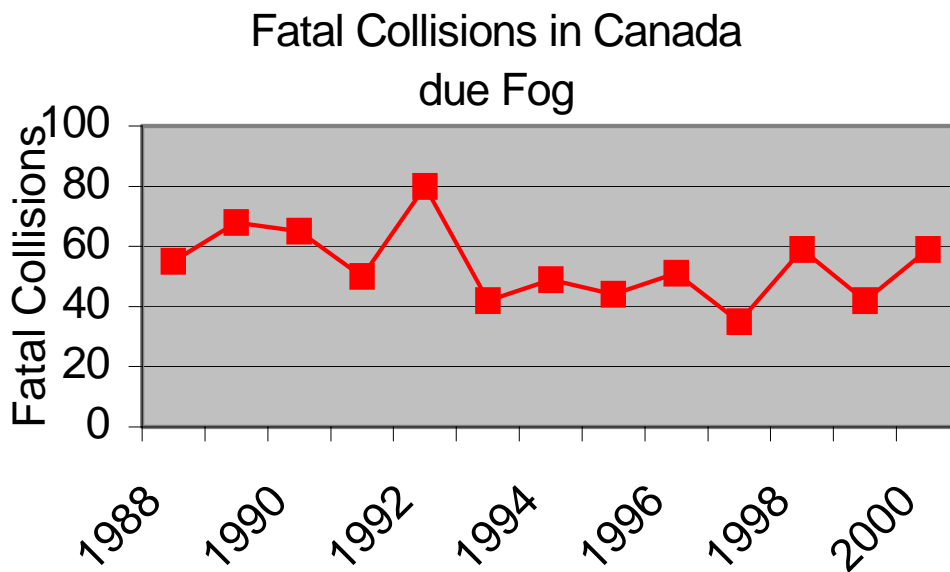

Figure 1. Fatal Collisions in Canada due Fog. (Transport Canada, 2001)

 Although the number of highway fatalities in fog pale in comparison to the total number of highway fatalities, a more useful comparison may be made with respect to the number of fatalities during other meteorological events.   As has been seen, 54 fatal collisions occur each year in Canada in fog/smog/mist conditions, while over 700 fatalities occur each year in the United States in dense fog.   In comparison, tornadoes result in an average of two deaths each

year in Canada (primarily a consequence of the Edmonton tornado, 1987 and the Pine Lake tornado, 2000), while in the United States, 70 persons are killed each year by tornadoes.

Although fog may not be the primary causal factor in all fatal collisions, it is clear from news reports of individual events that fog is a contributing factor in many instances.   On-scene reports of multi-vehicle pileups invariably cite fog as the primary or a contributing factor but fog may also play a significant role in many single vehicle accidents. On September 27, 2002, within one day of the Chambly and Winnipeg accidents, the media (Toronto Star, 2002) quoted the local constable with the Barrie Ontario Provincial Police as stating that dense fog was a contributing factor in the traffic death of a teenage girl.
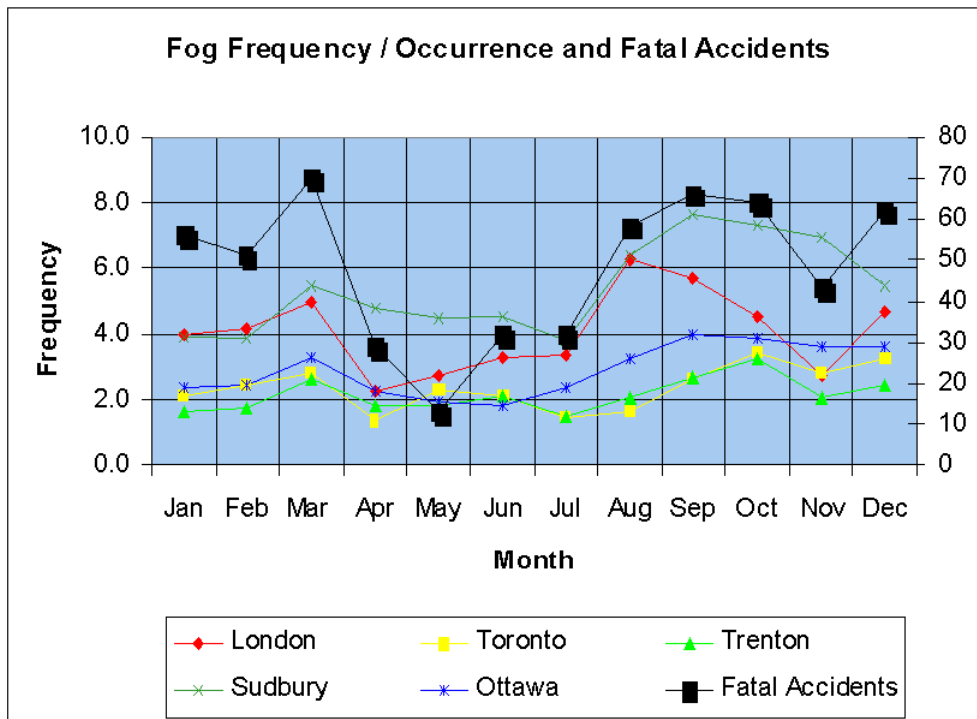

Figure 2. Comparison of Fog and Fatal Accident (due fog) Frequency by Month.

Figure 2 illustrates a remarkable correlation between the distribution by month of fog occurrence for a number of locations in Ontario with the average number of fatal collisions in fog.   Both trends show peaks in March, when advection fog and fog generated from melting snow are more common, and in late summer/early fall, when radiation fog is prevalent.   Also important of note is the absence of a fatal-accident peak during smog season (July/August), thus suggesting that although smog is included in the fatal-accident statistics, the majority of accidents occur in fog, not smog.

Moore and Cooper (1972) have shown that "thick fog" with visibilities of less than 150 meters begin to present a serious hazard to motorists.   Excessive speed under such circumstances can

lead to serious, often fatal, problems as drivers either loose their frame of reference or can no longer maintain sufficient spacing between vehicles. Radiation fog is particularly dangerous. According to Musk (1991), smaller droplet size and larger concentrations per volume of air disrupt the path of light (and therefore impact visibilities) more significantly than fog formed from other processes.   Radiation fog also forms suddenly, frequently near sunrise, in otherwise ideal conditions (i.e., clear skies, light winds) and therefore catch motorists by surprise. The transition from clear conditions to extremely low visibilities is much more abrupt than in other types of fog, or even other weather conditions.   Drivers are unaware of potential accidents further ahead and have little time to adjust their speed.   The potential for multi-vehicle pileups is obvious.

Channel Differencing Imagery to Detect Fog

The detection and short-term forecasting of fog poses particular challenges to the forecast community. These challenges arise from the fact that it is difficult to delineate fog areas of limited extent within the coarse surface network where stations may be 100 km or more apart. The problem becomes even more difficult at night because there are fewer stations in operation, and the probability of fog increases.

The advent of Multispectral Geostationary Satellites such as the US GOES (Geostationary Operational Environmental Satellite) has made it possible to monitor cloud conditions on a nearly continuous basis and aides in fog detection. During daytime fog and stratus areas can be detected directly using hours high resolution (1 km) visual imagery (Anderson, 1974).

However, it is more difficult to detect fog at night using satellite data. There are four main infrared channels on GOES with resolutions from 4 km on this platform. The infrared (IR) channels sense radiation which depends on the temperature of the emitting surface. Because the fog and the surrounding areas tend to have similar temperatures, the fog cannot easily be distinguished from surrounding clear areas for a given IR channel. This explains the difficulty in distinguishing fog areas using single channel IR imagery. However, it was found that water droplet clouds have markedly different emissivities (and hence apparent temperatures) in the 3.9 µm and 10.7 µm IR channels, but have similar emissivities from the surrounding clear areas. Thus, subtracting the two channels from each other results in apparent temperature differences of 2-5° C which gives a very good discrimination of fog and/or stratus banks.

Hunt (1973) developed the theoretical ideas behind this and Ellrod (1995) applied the technique to GOES data. The latter found that the channel difference technique was an effective night-time fog and stratus detector over a wide range of terrain and temperature regimes. However, once the sun rises, the Hunt-Ellrod method fails since the 3.9µm channel becomes contaminated with reflected sunlight.

On August 10, 2000, an upper disturbance brought some middle cloud, with occasional showers and thunderstorms, to Northern Ontario. Southern and Eastern Ontario were under the influence of a weak ridge of high pressure.

The 10.7 μm GOES satellite imagery at 09:44 UTC (Figure 3) clearly indicates the band of organized cloud over Northern Ontario associated with the upper disturbance. However, typically no cloud feature was distinguishable over Southern or Eastern Ontario to explain the presence of fog there. The 3.9u imagery (not shown) also did not show any significant feature over the same portions of the province.
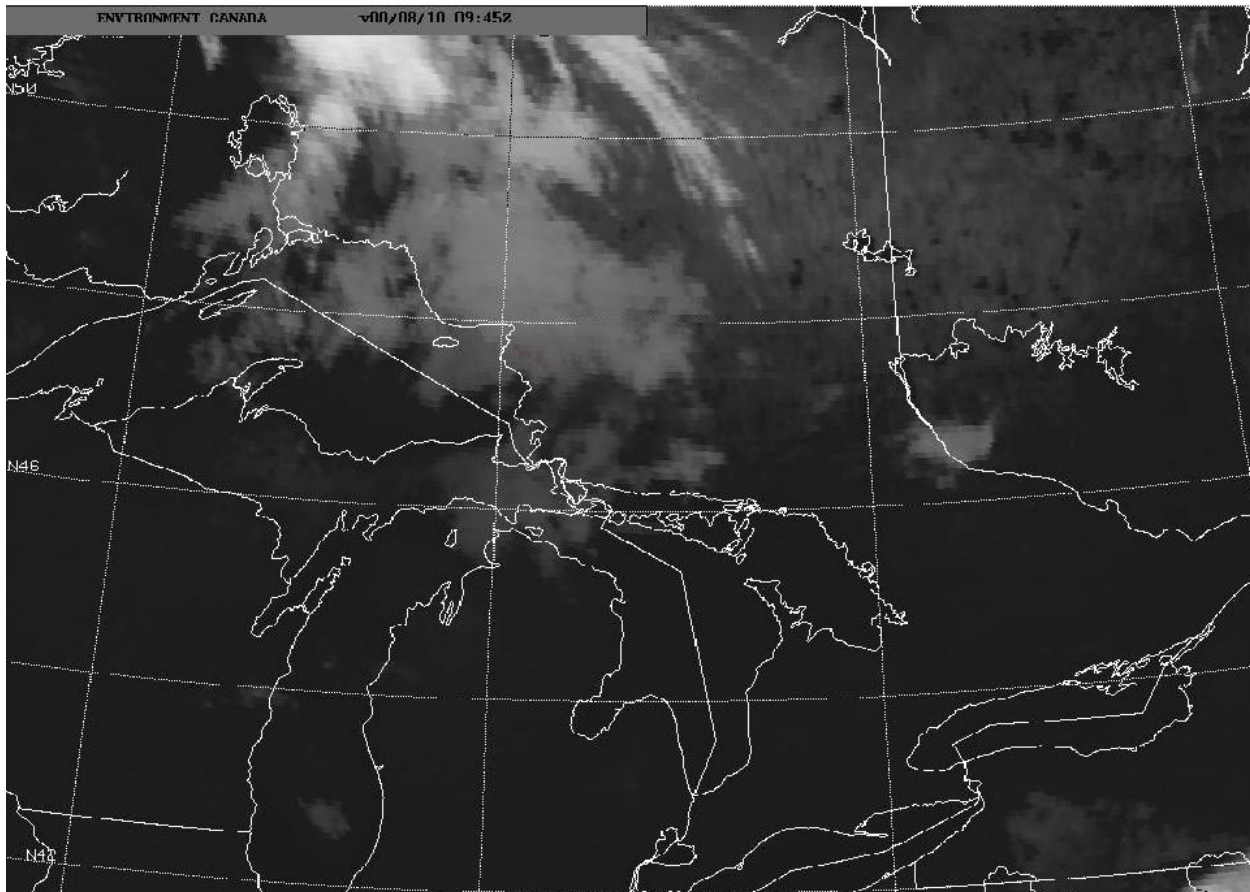

Figure 3: GOES 10.7u 10 August 2000, 09:44UTC

The FOG IR imagery derived using the approach developed by Ellrod is shown in Figure 4. This image clearly shows dark gray features which were not evident on the 10.7μm nor the 3.9μm imagery. Of interest are three bands: one near Ottawa (OW), another near Muskoka (QA), and a third between Wiarton (VV) and Hamilton (HM).
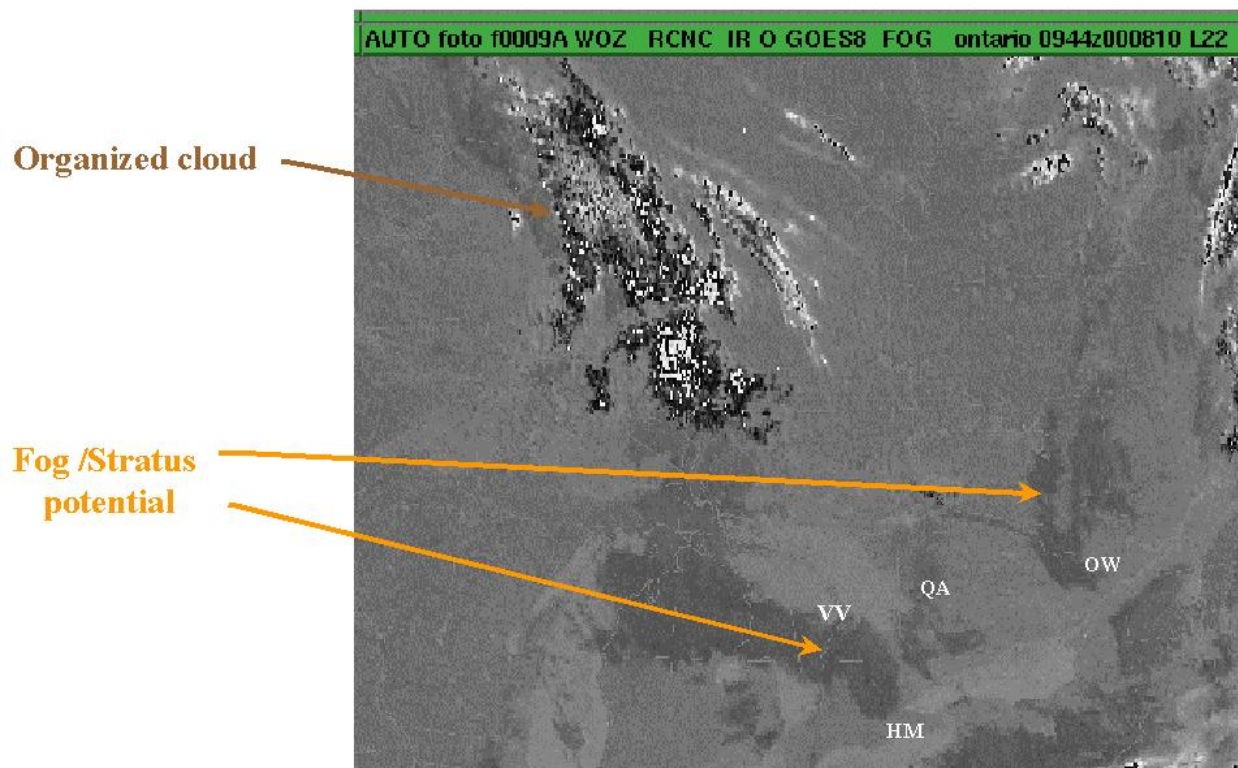
Figure 4: Fog Imagery taken at 09:44 UTC on August 10th, 2000.
Imagery calculated by taking IR temperature difference 10.7 and 3.9u
For fog/ Stratus T(10.7u) - T(3.9u) = 2-5C

The sun rose at 09:57 UTC over Ottawa, and 10:19 UTC over Hamilton. This renders subsequent channel difference imagery useless because of sunlight contamination as discussed above. Figure 5 shows the GOES visual image taken at 11:45 UTC, the earliest time for which a useful visual image could be obtained taking into account the sun elevation angle during morning hours. The resemblance with the 09:44 FOG image is remarkable. The mesoscale structure and position of the three bands discussed earlier is very similar. There were slight shifts in location however: the band which was north of Hamilton at 09:44 UTC drifted southward and was over Hamilton by 11:15 UTC.   This is consistent with observations taken at the airport locations. The band near Ottawa also appeared to drift southward.
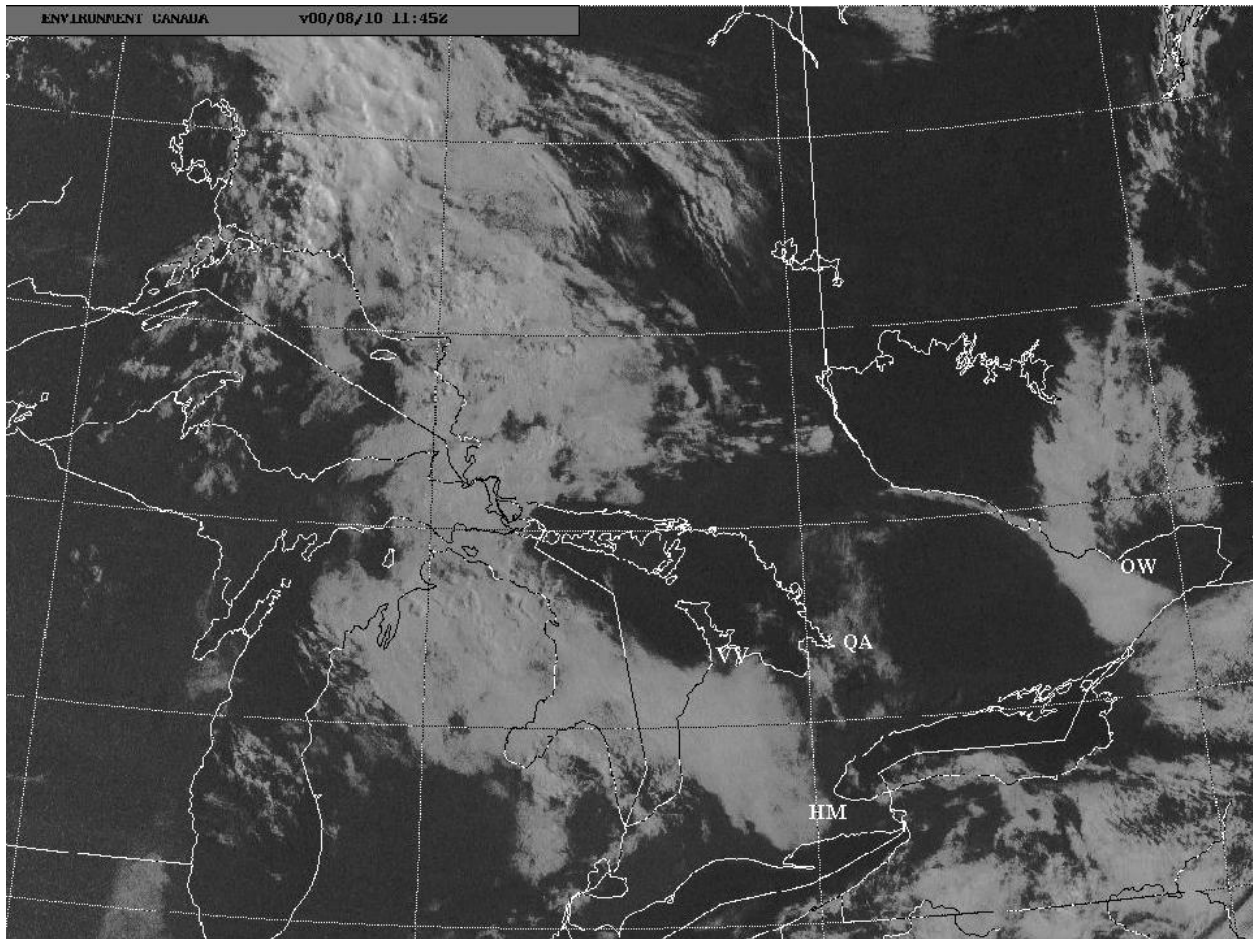
Figure 5: GOES Vis 10 August 2000, 11:45UTC

The similarity of the two images discussed above in conjunction with the airport observations shows that the Hunt-Ellrod Channel Differencing method is indeed a powerful tool for fog/ stratus detection. Understanding the synoptic situation and comparisons with in situ observations are nevertheless important since this approach cannot distinguish between fog and stratus per se. It works best in radiation fog situations, when there is no cloud present at higher levels. Finally, in some situations of precipitation or advection fog, the presence of cirrus or altocumulus impedes the effectiveness of this method as a fog detection tool.

Strategies for Mitigation

The foregoing analysis would suggest that a review of mitigation strategies for the growing impact of fog on road transportation should be undertaken. This exercise would require the participation of road transportation professionals and is beyond the scope of this paper. A suggested approach for such an exercise would be to use the Canadian Architecture for Intelligent Transportation System (ITS) as a framework. Very substantial effort from all sectors and disciplines over many years went into the development of the US ITS Architecture on which the Canadian architecture is based. In adopting the US ITS Architecture, Canada adapted it for Canada's specific needs. One of the two major changes was a much more formal and rigorous inclusion of weather elements through several new subsystems for Maintenance Management and Maintenance Vehicle.

The ITS Architecture affords a very complete and logical grouping of the major components in the road transportation mode along with the communications and other links between them. There are four major system groupings (Figure 6):
  1. Travellers;
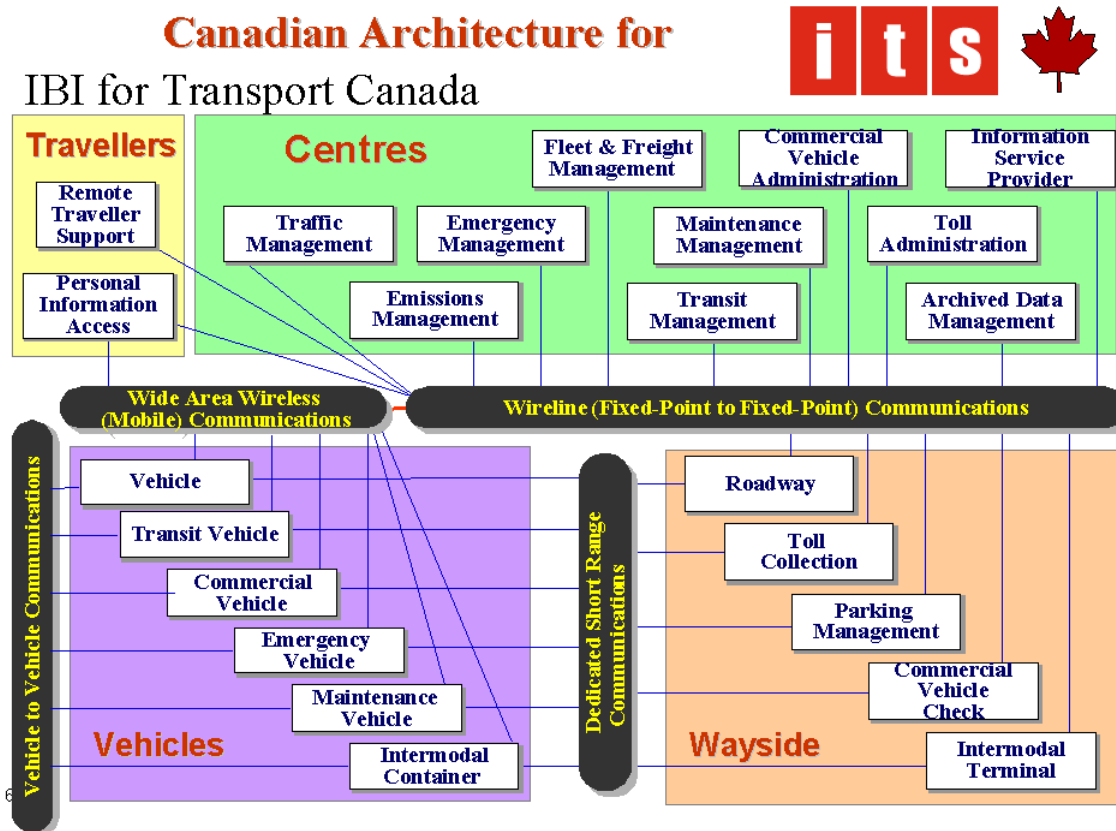 2. Vehicles;
  3. Wayside; and
  4. Centres.

Figure 6. The Canadian Architecture for Intelligent Transportation Systems

A review of mitigation strategies should include possible contributions from each of these systems and their sub-systems and how they will interact. To illustrate how such an evaluation might unfold, a few examples of some technologies and/or strategies that might be considered is provided. The reader is cautioned that this is by no means an exhaustive examination of options.

SAMPLE FOG MITIGATION STRATEGIES BASED ON THE ITS ARCHITECTURE

1. Travellers:
   - Increased driver education on appropriate behavior in fog;
   - Easier access to pertinent and friendly road weather information.

2. Vehicles:
   - Radar-based Adaptive Cruise Control Systems – expensive but potentially useful in evenly bringing down the speed of a group of vehicles – still leaves lane positioning uncertain for lone or lead vehicles;
   - Camera-based lane positioning system (Volvo research) – may be ineffective in zero-visibility fogs but requires little or no changes in roadway (Wayside);
   - Cadillac style night vision system – expensive and optimized for use in low light conditions and may be of only marginal use in low visibility conditions;
   - Simple European style rear fog light on all vehicles – would likely require legislation in multiple jurisdictions to implement so low cost but long lead time and substantial driver education required;
   - Extensively instrumented police cars which would be deployed to fog areas and used to lead groups of cars through dense fog – requires very effective alerting and rapid deployment.

3. Wayside
   - Magnetic tape based lane positioning systems – effective in even very dense fog but only for positioning (not spacing of vehicles) and requires addition of magnetic strip to entire length of heavily-travelled roadways and magnetic sensors in all vehicles;
   - Deploying Road Weather Information Systems (RWIS) to acquire temperature, humidity, and wind readings from the roadway to assist in the detection of fog and provide data to better predict fog to pursue other measure pro-actively;
   - Including visibility sensors either separately or as part of RWIS systems to provide accurate visibility readings – expensive, reactive only, and requires careful study of fog and transportation circumstances to position optimally – likely will not detect all serious fog occurrences;
   - Variable message or speed signs triggered by RWIS or visibility sensor readings to slow traffic – expensive and unless positioned perfectly, not effective for very dense fog;
   - Reflectors or LEDs (solar-powered) sunk into roadway – expensive but effective in providing frame of reference for all but zero-visibility fog – careful study required to deploy effectively;
   - Using the extensive video cameras already in place along with artificial intelligence to assess visibilities at multiple sites – close coordination between multiple agencies required and will always miss some serious fog occurrences.

4. Centres
- Various centres receive portions of useful data
  - Maintenance Management receives RWIS data
  - Traffic Management receives video images and lane occupancy and speed information
  - Tool Administration Centre may have many video images as well
- Various centers need information on fog:
  - Traffic Management to slow traffic where possible
  - Emergency Management (includes police) to deploy lead vehicles
  - Information Service Provider to provide useful data to the motoring public
- The Weather Service Provider (private sector) may be able to provide road specific fog forecasts and warnings using some of the data above together with data from the national weather service.

The advent of ITS, which uses existing detection, computer, and communications technology in new integrated powerful ways to make traffic flow smarter, smoother and safer is seen as a major part of the solution to increasing congestion on our roads. All of the developed countries have developed ITS or "Informatics" architectures to deploy these many technologies in a carefully orchestrated manner. The world ITS industry is expected to boom in the coming years. We have seen in other modes of transportation that with increased technical sophistication, weather dependence increased rather than decreased. The same trend appears to be emerging in the road transportation mode. Care must be taken to ensure that important safety issues are not overlooked.

The current accident reporting forms and procedures completed by enforcement officers are vital to understanding the impact of weather on accidents and fatalities. However, there may be room for some improvement in order to isolate specific weather parameters and the extent to which these are not only present, but causal as well. Three obstructions to visibility are grouped together on the reporting forms: fog, smog, and mist. In a meteorological sense, these phenomena are quite different. The definition of fog within the meteorological community requires visibilities of less than one kilometre; visibilities in mist and smog can be much higher. There may be differences across the country with respect to training on meteorological factors, and the extent to which meteorological elements are "causal" may need to be further refined. A dialogue with the enforcement community may improvement our capacity to isolate the true impact of weather conditions on accidents and fatalities.

Conclusions

Fog has played a contributing or even causal role in several multi-vehicle accidents over the past several years. While statistics suggest that highway accidents and fatalities, in general, have fallen, that trend is not evident with respect to accidents/fatalities in fog. In fact, changes in urban traffic may exacerbate the problem. A multi-partner approach towards developing a strategy for addressing the impact of fog on highway transportation is required.

Acknowledgements

References

Anderson, R. K., and co-authors, 1974: Application of meteorological satellite data analysis and forecasting. ESSA Tech. Report MESC 51, U. S. Dept of Commerce, Washington, DC, p. 6-B-1

Andrey, J. and A. Snow, 1998.   In Canada Country Study: Climate Impacts and Adaptation, National Sectoral Issues. Transportation Sector. Volume 7. Chapter 8. Environment Canada.

Ellrod, G. P., 1995: Advances in the detection and analysis of fog at night using GOES multispectral infrered imagery. Weather and Forecasting, 10, 606-619.

Hunt, G. E., 1973: Radiative properties of terrestrial clouds at visible and infrared thermal window wavelengths. Quart. J. Roy. Meteor. Soc., 99, 346-369– Marine.

MacIver, Don C. and Heather Auld: Weather Hazards and Changing Road Conditions in Ontario, Canada, 24th Conference on Agricultural and Forest Meteorology, 14th Conference on Biometeorology and Aerobiology & Third Symposium on the Urban Environmnet, 14-18 August, 2002, Davis, CA, USA.

Moore, R.L. and L. Cooper: Fog and Road Traffic.   Transport and Road Research Laboratory Report 446. 1972.

Muraca, Giuseppe, D.C. MacIver, Natty Urquizo, Heather Auld: The Climatology of Fog in Canada, 2nd International Conference on Fog and Fog Collection, 15-20 July 2001, St. John's, NL, Canada.

Musk, Leslie F. Highway Meteorology, Chapter 6. The Fog Hazard, pp 91-130 E & FN Spol 1991.

Snowden, R.J., N. Stimpson, and R. A. Ruddle, 1998: Speed perception fogs up as visibility drops, Nature, Volume 392: 6607, pg. 450 (1).

The Toronto Star, September 27, 2002, A23.

Transport Canada: Trends in Motor Vehicle Traffic Collision Statistics, 1988-1997, prepared by Road Safety and Motor Vehicle Regulation Directorate, February 2001.

Transport Canada: Road Safety Vision 2010, Update 2001, June 2002.