OPERATIONAL RESILIENCE IN MAINTENANCE DECISION SUPPORT SYSTEMS

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ABSTRACT

Given the non-linear and dynamic nature of weather systems, it is inevitable that errors in weather forecasting will occur. Some of these errors can have significant operational impact on winter service activities. In developing maintenance decision support systems, care must be taken to allow for such errors, by creating systems that are resilient when such errors occur. The lecture will explore both the types of errors that can occur and possible ways of making sure that forecasting errors do not create operational calamities.

While there are numerous ways in which a forecast may be in error, some of these errors pose more of an operational challenge in the area of winter service than others. In particular, errors in prediction of storm start times, of precipitation type (snow, sleet, freezing rain), and surface temperature can have significant impacts on operational actions and on road surface conditions. These operational impacts are explored in detail.

Given the inevitability of forecast errors, it is imperative that decision support systems be sufficiently resilient to allow for the errors. This resilience can be achieved in one of two ways. First, the link between decisions and forecast can be somewhat decoupled, and second, feedback of real time information on road surface conditions can be enhanced.

Decoupling the link between forecast and decisions can be done either manually or automatically. If done manually, essentially the supervisor using the decision support system can adjust the forecast so as to examine how small changes in forecast behavior may or may not require radical changes in operational actions. If no radical changes are observed, then small errors in the forecast will likely have little effect. This process can be done automatically, but if so then the forecast must be expressed in such a way that it can be represented by way of a matrix. Then the forecast can be adjusted from that given by moving one „cell“ in each direction for each „dimension“ of the forecast matrix. This idea is explored further in the presentation.

INTRODUCTION

Winter maintenance is a most important highway activity, insofar as it helps to ensure the safety and mobility of the travelling public. Studies have shown that road closures carry real and significant costs to the economy. For example, a one-day shut down in the State of Michigan has direct costs of US$115m and derived costs of US$144m [1], while for the state of Iowa, a one-day shut down has direct costs of US$27.9m and derived costs of US$34.8m [2]. The Washington State Department of Transport (DOT) reports that when avalanches on Snoqualmie Pass forced the closure of I-90 from 29th January through 2nd February, 2008, this resulted in a total economic loss of US$27.9m, and a loss of state tax revenue of US$1.42m; the loss per hour was approximately US$230,000 [3]. Further, the major East Coast storm in January 1996 is estimated to have cost the US economy about US$10bn [4]. Lin and Nixon [5] showed that the presence of snow on the road increases the likelihood of a fatality by 9% (compared to a dry road) and the likelihood of a crash by 84%. Even though winter maintenance in the United States has advanced significantly over the past twenty years, the US Federal Highway Administration estimates that there are 2,200 fatalities, and 192,500 crashes annually due to winter weather [6].

The degree to which the practice of winter maintenance has improved in the US over the past two decades is borne out not only by improved crash rates over time [5] but also by studies, such as by Breem [7] which showed an 83% reduction in crashes as a result of using a pro-active anti-icing winter maintenance strategy. Given these sorts of results, there is clearly great interest in using pro-active anti-icing as the primary winter maintenance strategy in the US. The challenge in using anti-icing is that maintenance actions are determined by the weather forecast. In order to pre-treat a road system, or part of such, with liquid ice control chemicals prior to a storm, that storm must be forecast, and the forecast must identify a number of factors that may not be part of a normal forecast, but are critically important from the point of view of winter maintenance. From this it follows that an incorrect forecast can give rise to an incorrect maintenance action. The purpose of this paper is to examine how decision support systems can be made robust and resilient to forecast errors, without sacrificing the benefits of pro-active maintenance actions.

FORECAST ERRORS

There have of course been a number of studies on forecast errors and how they can be measured. For example, Barnes et al. [8] note that the False Alarm Rate (FAR) for winter storms in the US from October 2004 through September 2005 was 0.31, suggesting that in general false alarms of winter storms are not very common. However, this information alone does not clarify the degree to which winter storm forecasts are operationally accurate.

The notion of operational accuracy is somewhat new and requires some explanation. For a storm forecast to be operationally accurate, it must accurately predict those aspects of the storm that have significant operational importance. Table 1 lists the major aspects that must be correctly forecast, together with the factors of winter maintenance that will be impacted by an incorrect forecast. None of these factors in table 1 are likely to be captured by any of the current models dealing with forecast errors, and as such a new approach will be required if winter operations are to be made resilient in the face of inevitable (even if rare) forecast errors. Of course, there is a base “value” of resilience that can be achieved simply by not using pro-active (i.e. anti-icing) winter operations

strategies, but as noted above, such pro-active strategies are much better in terms of safety and mobility than reactive maintenance strategies.

Winter Storm Aspects of Operational Significance	Factors Impacted by an Incorrect Forecast
Storm start time	Scheduling of personnel, timing of applications, especially with respect to rush hours
Storm duration	Scheduling of personnel
Precipitation type	Appropriate chemical treatment, and in particular, appropriate pre-storm treatment
Wind speed, during and after storm	The use of liquids, either directly or as pre-wetting, especially at the end of storms if drifting is possible
Pavement temperature	Application rates, and selection of materials
Pavement temperature trends at the end of a storm	The use of pre-wet chemicals towards the end of a storm

Table 1: Winter Storm Aspects that Most Impact Operational Actions

With regard to storm start time, knowing this with accuracy allows for a proper rotation of personnel to be established prior to the start of an event. Combined with a knowledge of storm duration, personnel can then be deployed optimally to obtain desired levels of safety and mobility during a storm with the available resources. Errors in either storm start or storm duration can result in circumstances in which required personnel are not available, and inevitably a reduced level of service will occur in such cases.

Storm start time can also be particularly important in urban areas, or indeed any location in which morning and evening traffic levels are particularly high for the road system. Speeds of vehicles in rush hour conditions are of course much lower than in normal conditions, and thus more time must be allowed for a complete treatment of a road system if this must be done during rush hour. If a storm begins during rush hour times, then plowing at that time will be slowed and appropriate modifications (e.g. assigning more trucks) will need to be made to the snow plan.

Clearly precipitation type has a significant impact on how a storm is fought, primarily because different types or intensities of precipitation may require different chemicals. A freezing rain event cannot typically be effectively managed with direct liquid application, unless levels of precipitation are extremely low. Thus a storm in which snow is predicted but in which freezing rain actually occurs is likely to pose severe operational problems, because any pre-treatment of the road system with liquids is likely to become ineffective within minutes of a freezing rain event beginning.

Wind speed is of paramount importance once it gets to a speed at which drifting is likely to occur (about 20 mph or 30 kph). In such situations, drifting snow will stick to any wet roads, dilute out the chemicals there, and give rise to ice very rapidly. Thus, if wind speeds are likely to be high, chemical treatments must be such as to keep the road as dry as possible through the storm. This can become especially critical in storms where wind speeds may increase after the storm. Failure to dry out the road rapidly enough under these circumstances can lead to a need to continue road treatments for many hours or even days after the storm has ended.

Pavement temperature is obviously a major concern because it can impact both the type and the quantity of materials required to fight the storm effectively. Practice in the US limits the use of salt

(sodium chloride) once surface temperature drop below about 15° F (-10° C). Clearly, if pavement temperatures are expected to drop below this level for significant amounts of time during a storm then a different chemical will be needed. Again, as temperatures decrease, greater quantities of chemical are needed. At the end of the storm, a rapidly dropping temperature (a relatively common occurrence in the Midwest United States) requires that the road be made as dry as possible, to minimize the likelihood of freezing of the chemical on the road.

DEVELOPING SYSTEM RESILIENCE

The nature of the forecast challenges associated with winter maintenance operations is twofold. There is an issue that is time related (start and end time) and an issue that is weather related (temperature, precipitation type and wind speed). The two domains (time and weather) require different approaches to develop resilience.

RESILIENCE IN THE TIME DOMAIN

Resilience in the time domain will have two aspects for consideration. The means to develop resilience will vary for individual organizations, often quite considerably, so no definitive solution can be provided here, but a method can be described that can develop such a solution. Timing impacts, broadly speaking, three aspects of storm fighting. These are rush hour applications, shift starting times, and for longer storms, shift switch over and scheduling. Communications between forecasters and winter maintenance managers will be key to developing resilience here, and in particular, forecasters must provide warnings in a number of cases.

First, a forecaster should provide a special warning for (or "flag") a storm for which operations will last longer than a certain period. If shift times are limited to 12 hours for operators prior to a mandatory break, for example, then any storm lasting longer than 6 to 8 hours should be flagged as a multi-shift storm. This allows time beforehand for pre-treatment, and a relatively small time frame for errors in start time. Obviously, other maximum shift times will require different storm lengths for triggers.

Second, forecasters should attempt to provide a window within which they are reasonably certain that the storm will begin. Thus, instead of "the storm will begin at 6 a.m." a more appropriate forecast would be "the storm will start between 3 a.m. and 9 a.m." However, this area definitely requires refinement. It would be very valuable if a certain level of probability could be assigned to the storm start time, such as "the storm will start, to a 95% level of probability, between 3 a.m. and 9 a.m." It is unclear whether such probability levels can be assigned at present.

Third, forecasters should "flag" storms that are likely to start at times such that rush hours will impact pre-storm and early storm operations. The times for which these flags would be needed will vary for different organizations, since different organizations need different amounts of lead time to complete a pre-treatment (for example) and lead times may also be considerably different for morning and afternoon rush hours. In the US, the afternoon rush hour tends to begin around 3 p.m. as students start to leave school, and school buses need to be accommodated. In other countries, the afternoon rush hour may be less spread out. Using these three methods will provide as much "protection" as possible for winter service organizations with respect to the time domain. However,

it should be noted that no such system can ever be 100% fool proof. Even with such systems in place, problems will still occur.

RESILIENCE IN THE WEATHER DOMAIN

Resilience in the weather domain can be achieved by determining a series of descriptive boundaries between different weather conditions and then assigning different treatments to the weather conditions found on differing sides of the boundaries. If the treatment required shifts significantly across a boundary, then that boundary must be considered carefully in any forecasts, and should a shift of forecast across that boundary be sufficiently likely, steps should be taken to minimize any negative consequences of such a shift.

Figure 1 shows how a storm can be described in terms of such boundaries. It is in short a matrix based description of a winter storm [9]. A storm can be described, fairly accurately from an operational point of view, by selecting one "value" from each category. Resilience can be improved by considering which boundaries would have significant impacts on operations. Thus, in the category of storm type, the difference between a light and a medium snow storm is minimal, while the difference between a light snow storm and freezing rain is very significant from an operational point of view.

In terms of resilience, the following boundaries are of significance. In category 1 (storm type) the boundary between freezing rain and any other storm type is significant. In category 2 (in-storm temperature) the boundary between cold and mid-range temperatures is significant. The boundaries between the two options in categories 3, 4, and 6 are significant, although in category 4 this boundary is less significant than in the other two categories. And finally, in category 5, the boundary between cooling temperatures post-storm and the other two categories is significant. Forecasts would be significantly improved operationally if these boundaries were recognized and "flagged" at the time of the forecast being proved, should these boundaries be "in play" at that time. This would allow storm managers to determine whether to use a strategy that might be sub-optimal should the forecast weather occur, but would not be a bad selection should a condition on the "other side of the boundary" occur instead.

DISCUSSION AND CONCLUSIONS

While inevitably, forecasts will be in error from time to time, by considering the particular forms of these errors, it is possible to minimize the operational impacts of these errors. Methods have been presented by which these impacts can be minimized. While clearly further work is required in this regard, this nonetheless represents a first step toward minimizing the negative consequences of incorrect forecasts.

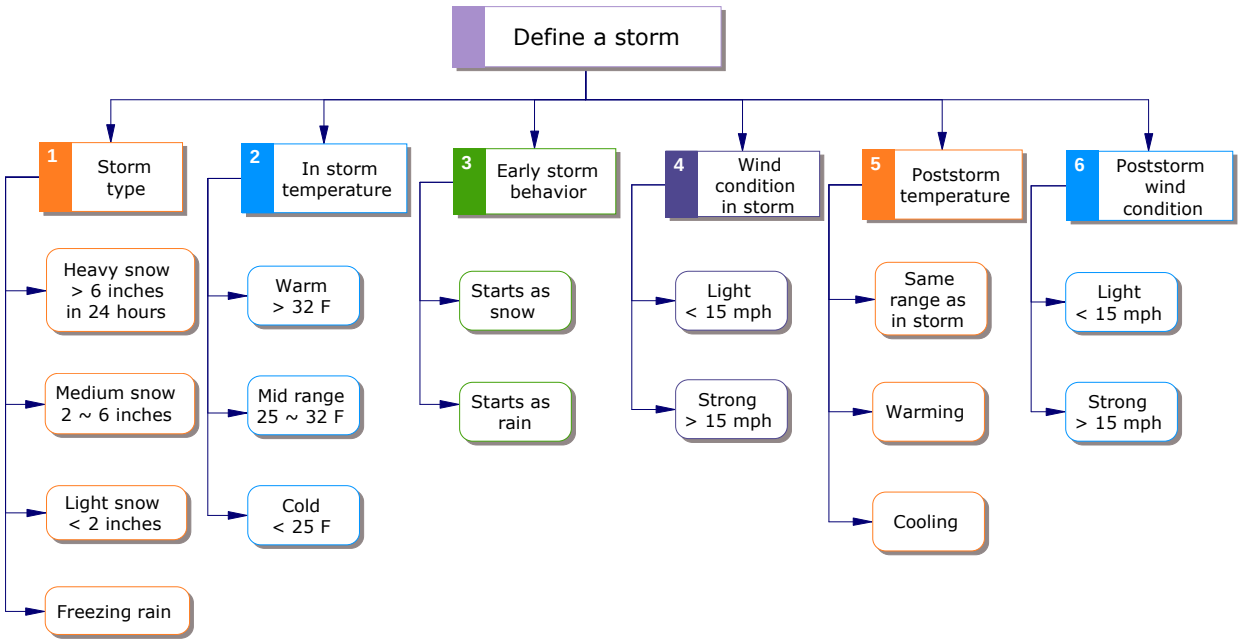

Figure 1: A Matrix Based Storm Description.

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