XRWIS: A NEW PARADIGM FOR WINTER ROAD MAINTENANCE

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ABSTRACT

The use of Road Weather Information Systems (RWIS) for the winter maintenance of roads is now widespread around the world. Road weather forecasts can be compared with road surface temperatures and road condition on an hour by hour basis. However the road weather forecasts are only normally made available for a limited number of road sensor sites in a region. For example in Birmingham, in the UK, there is one forecast site for 26 salting routes. XRWIS is the NeXt Generation Road Weather Information System that forecasts for every 20 metres around each salting route using a geographical information system, sky-view factor analysis and mesoscale weather forecasts. Treatment requirements for each salting route are then visualised in simple 'traffic-light' style colours and a map is displayed on the internet. In a recent trial in Devon in England, for 152 nights in the winter of 2004/05, the XRWIS energy balance model 'IceMiser' was run for more than 12,000 locations around 6 salting routes compared to just one forecast site that is normally used. If the XRWIS system had been operational up to 78 salting runs on those six salting routes could have been saved.

Keywords: Road Weather, Mesoscale, XRWIS, Sky-View Factor

1. INTRODUCTION

The current paradigm in the United Kingdom (and most other countries with cold winter climates) for the prediction of ice and snow on roads was developed in the 1980's by the University of Birmingham and the UK Met Office for the benefit of highway engineers [7]. Currently in the UK, about £150m is spent in an average winter, to spread salt to prevent ice formation and remove snow from our major roads. Around the globe approximately $10 billion are spent every winter to keep roads open and safe. Without the current Road Weather Information Systems (RWIS) the cost of winter road maintenance would be much higher and there would be many more accidents and delays on slippery roads in winter. Today there are more than 200 Highway Authorities (HAs) responsible for the winter maintenance of roads in the UK. More than 1000 road weather outstations have been installed and virtually all salting routes have been thermally mapped [6]. In total there are more than 3500 Salting Routes in the UK and approximately 120,000km (30% of the 400,000km) of main roads in the UK are salted. Each cold night in winter we spend about £3m to keep the nations roads open and we spend about £1250/km each winter to keep our main roads open and safe. Thornes [8] has shown that for every £1 spent on winter maintenance about £8 are saved and hence we could be thinking that the current paradigm is perfectly adequate – but the methodology behind the current RWIS is 20 years out of date – technology has moved on and we can now reduce costs and improve performance by updating our current systems to the next generation road weather information system - XRWIS.

2. THE CURRENT RWIS PARADIGM IN THE UK

If salt can be spread on our roads before ice forms then much less salt is required (Presalting at 10 g/m^2) than if the ice has to be melted by the salt (De-Icing at 40 g/m^2). Similarly if salt is spread in advance of snowfall (usually at 40 g/m^2) then small amounts of snow will be melted quickly by the salt, and greater amounts of snow can more easily be removed as the snow will have been prevented from freezing onto the road. Hence the need for accurate weather prediction so that winter maintenance activities can be proactive rather than reactive.

In the early 1980s, before the widespread use of RWIS, the Met Office used to issue Road Danger Warnings to Highway Authorities [5]. These would be simple statements such as:

Road surface temperatures are expected to fall below zero at 2am and ice is expected to form on most of the roads in the region.

These warnings were usually sent by fax to HAs and were effectively issued at cost.

In the early 1980s what were called 'Ice Detection Systems' were introduced to the market. These comprised a number of road weather 'outstations' which could be interrogated by an 'instation' computer at a HAs central depot. However these systems could only detect when ice had formed on the road sensor by which time it was too late to presalt the roads. Also the output from these sensors could be misleading as salt is hygroscopic. For example if an ice detection system is giving a 'Critical' warning when the road surface temperature falls below zero and the road is 'wet'. If the road is 'wet' due to residual salt going into solution as the air humidity rises above 80 % then this 'false alarm' could lead to the road being salted again unnecessarily!

Another problem was that the road sensor is only able to give the road surface condition and temperature at one location within a few centimetres and it was not known how representative this was of the rest of the road network. The concept of Thermal Mapping was developed in the UK at the University of Birmingham to give a spatial estimate of the likely minimum road surface temperature along a route. The first commercial thermal map was produced for the A9 in Highland Region in 1984. Also at this time the concept of climatic zones within a HA was developed based on thermal map data.

In the remainder of the 1980s a flurry of activity led to the installation of what are called 'Ice Prediction Systems' in HAs. The concept was an improvement over ice detection for a number of reasons. Firstly the Met Office in conjunction with Thermal Mapping International (TMI was a spin-out company from the University of Birmingham) developed a new forecast product to replace Road Danger Warnings called Open Road. Using a road energy balance model, a 24 hour prediction of road surface temperature and condition could be transmitted to HAs in the early afternoon based on noon measurements from the road sensors and weather forecast models. A forecast graph, from noon to noon the next day, for a road sensor in each climate zone also enabled the timing of when the road surface temperature was likely to fall below freezing to be seen. As the road sensor data was recorded each hour this was then plotted on the forecast graph to give the engineer feedback as to the accuracy of the forecast. If the road surface temperature forecast was more than 2^{o}C different to the actual and the road surface temperature was below 5 ^{o}C then the forecast graph would be updated. Secondly forecast thermal maps were calculated depending on the air stability (extreme, intermediate or damped) for each climate zone. The minimum road surface temperature was forecast and maps of the road network colour coded to show which roads were likely to fall below zero. Thirdly the National Ice Prediction Network (NIPN) was developed to enable weather forecast providers to communicate with any sensor manufacturers instation software and provide additional features such as weather radar and satellite pictures.

It soon became apparent that most HAs would prefer their RWIS to be maintained and monitored by the system suppliers. Hence the concept of the 'Bureau' was developed. The National Ice Prediction Network (NIPN) was then complete.

This system has spread across the whole of the UK and around the rest of the world. When it was developed it was considerably more advanced than any other weather forecast user product but the concept was limited by the speed of computers and communications. In the mid 1980s it took 30 minutes to run the Fortran energy balance model for one location. The modems used to collect the road sensor data often took several minutes to connect to each outstation and were unreliable and slow. The fixed climate zones and thermal map types were necessary simplifications to make the system usable in real time.

During the 1990s and up to the present day the NIPN – RWIS has speeded up communications and the internet has been used to access the sensor and forecast data. However the basic system has not changed and is dated and in need of regeneration.

3. NEXT GENERATION ROAD WEATHER INFORMATION SYSTEMS: XRWIS

The Road Weather Information System developed in the UK in the 1980s has provided highway engineers with reliable road weather forecasts for almost 20 years. The system architecture provides the highway engineer with site specific forecasts for normally one sensor site in each climate domain. The highway engineer then has to convert this information into a decision as to which salting routes need to be treated, at what time and with how much salt. This is a difficult decision as the engineer may have anything up to 48 salting routes as in Devon. In Birmingham forecast data for one outstation is used to decide which of 26 routes need salting. This can lead to considerable problems at times of severe winter weather [9].

XRWIS is a simple new intuitive concept (Figure 1) that provides a separate road weather forecast for each salting route and gives an initial prediction as to which routes require salting, why they require salting, at what time and with how much salt. A visualisation is given in Figure 2d – simple 'traffic light' colours (red=salt; orange=standby and green=no action). As can be seen in Table 1 the expected minimum road surface temperature is given for each salting route together with the optimum time for salting of the red routes. This information can be presented to the highway engineer for all salting routes in a region or split into divisions as required. The engineer can then 'click-on' a coloured route to see a forecast graph for the coldest point on that route and forecast road temperature and condition as shown in figure 2. The front-end map will be updated as required by the user.

On many nights all the routes will be red and XRWIS will give the time, reason and salting requirements for each route. On other nights all the routes will be green and no action will be necessary. On several nights a combinations of colours will appear which will reflect a marginal night – signalling that the system will need to be monitored through the night. The thresholds for colour coding can be agreed with each highway authority when the system is installed and fine tuned over time using a self-learning neural network approach.

Ideally the route based forecasts will be driven by a mesoscale weather forecast model which typically operates with a 10km grid. The relevant grid point will be chosen for each salting route – or a combination of grid points. This will ensure that the best forecast is made available for each route.

The secret to the success of XRWIS for route based forecasting is the construction of a geographical database for each salting route [1,2]. A sky-view factor survey (or thermal geomatic survey if it is combined with thermal mapping) is carried out to provide the proportion of visible sky at 20m intervals along the route. The sky-view factor controls the energy balance of the road surface (1=open sky; 0=tunnel) and measures the presence of buildings and trees and other topographic features [3,4]. The database also contains other geographical and road data (Figure 1) for each 20m stretch (latitude, longitude, altitude, slope, aspect, road construction, thermal map residual temperature, land-use, and traffic volume)

XRWIS then combines the mesoscale weather forecast with the microclimate of each salting route to predict whether or not the route needs treating. Each night is taken on it's own merits and there is no need for fixed climate zones and restrictive thermal map types. An energy balance model (IceMiser) is run for every 20m of road and predicts the road surface temperature and condition every 20 minutes. An additional feature shows a 'league table' of salting routes on a given night – ranking the routes from the one that needs salting first to the one that needs salting last. This thermal ranking of routes is very important and will reflect the geography of each route as well as the predicted weather conditions on each night.

In snow situations XRWIS will show the expected snow accumulation for each salting route and the required timing and amount of salt required. Alerts for the use of snow ploughs and snow blowers will be given as an additional layer of information.

The new thermal geomatic surveys (TGS) also enable more efficient salting route optimisation, and could lead to future developments in selective salting of routes and dynamic routing.

4. VERIFICATION

During the winter of 2004/05 a trial of XRWIS Route Based Forecasting was initiated for Devon County Council. The trial involved forecasting whether or not six salting routes required treating using the simple 'traffic light' colour coding, on a night by night basis. Eight road sensor sites were chosen for verification. A Geographical Information System (GIS) database for each salting route was constructed from a Thermal

Geomatic Survey of each route. The UK Met Office supplied the weather forecast data which was based on the 0600 and 1200 run of their mesoscale model. Each salting route had a separate forecast. XRWIS predictions were compared with Devon's sensor data from the 1st December 2004 until 30th April 2005 – a total of 152 nights. (Data for some nights was missing but at least 144 nights were available for analysis). The trial involved the calculation of road surface temperature for more than 12,000 locations. The forecast minimum road surface temperature for the nearest point to the 8 sensor sites was extracted for each night and compared to the minimum observed road surface temperature and the results for the 1200 run are presented in Table 2. Also the average minimum road surface temperature (Typical) for each salting route was calculated and compared to the minimum road surface temperature for each sensor site for 121 nights (1st December 2004 – 31st March 2005) and the results are given in Table 3. Devon salted their eight sensor sites a total of 329 nights but only on 220 nights did the road surface temperature fall to zero or below. XRWIS predicted that the sites should have salted on 251 nights – which would have meant 78 fewer salting runs.

This trial has been a great success in showing the benefits of the new XRWIS paradigm for predicting which salting routes should be treated. The 'Typical' (Realistic) forecast, based on the average forecast road surface temperature for each route, is probably the best approach in that it considers the entire route and is based on more than 2000 model runs per salting route. Forecasting for the sensor site alone can be misleading depending upon the location of the sensor site.

The XRWIS forecasts did not use road sensor data to initialize their forecasts. This means that reliable forecasts for each salting route can be made without the use of sensor data. The sensors are only used for verification. This new comprehensive route based forecast approach to road weather forecasting will revolutionize decision making in winter maintenance over the next few seasons.

5. CONCLUSION

XRWIS presents a new intuitive route based prediction system that gives the highway engineer all the information required to make the correct salting decisions. The delivery is via the internet with password protection and the geographical database can be built very quickly and economically to enable the microclimate of each salting route to be compiled. The use of virtual outstations and the latest mesoscale weather forecasting models will ensure more accurate salting decisions - reducing both costs and delays as well as improving safety.

The most important potential benefit of XRWIS is that it will lead to more uniform decision making across a region or country. Currently highway engineers make their own decisions as to which routes to salt based on their own RWIS installation and experience. XRWIS will potentially use standards agreed across a region such that every highway engineer in a region would potentially make the same decision for the same weather conditions. The experience of the highway engineers can be built into the algorithms that colour code the salting routes and estimate the time of salting and amount of salt to be used.

It will soon be possible to simultaneously forecast for all 3500 salting routes in the UK in less than an hour. This information would then be disseminated to the relevant regional highway engineers who would get a picture of the predicted nights weather across the whole country as well as in their own region. In the event of severe winter weather it would be possible to monitor the forecasts nationwide and share updated information across the country. For example during the severe winter weather of January 28th 2004 [9], when a squall line developed in front of a cold front bringing Arctic air down from the North, information on the severity of the event could have been forwarded to highway authorities to the South several hours in advance.

Like any new paradigm XRWIS will continue to use the best parts of the old RWIS paradigm. Indeed all the components of the old paradigm will still be there. XRWIS builds on the current paradigm to give the highway engineer many more layers of information to help make the correct salting decisions. The intuitive front-end visualisation of which routes need to be salted on a given night - synthesises the geography and microclimate of each salting route with the latest mesoscale weather forecasts. XRWIS route based forecasting provides all the information that the highway engineer needs.

With increased concern about litigation highway engineers need to be proactive to ensure that they have the best technology available to them. Highway Authorities 'are under a duty to ensure, so far as is reasonably practicable, that safe passage along a highway is not endangered by snow or ice' (Railways and Transport Safety Act 2003). XRWIS will ensure that the latest cutting edge technology is being applied to the problem.

6. REFERENCES

[1] Chapman, L. & Thornes, J. E. & Bradley, A. V. 2001a Modelling of road surface temperature from a geographical parameter database. Part 1: Statistical, Meteorological Applications, 8: 409-419.
[2] Chapman, L. & Thornes, J. E. & Bradley, A. V. 2001b Modelling of road surface temperature from a geographical parameter database. Part 2: Numerical, Meteorological Applications, 8: 421-436.
[3] Chapman, L. & Thornes, J.E. & Bradley, A. 2002 Sky-View Factor Approximation using GPS Receivers, *Int. J. Climatol*, 22, 615-621
[4] Chapman, L. & Thornes, J.E. 2004 Use of neural networks to improve GPS Sky-View Factor Approximation, *Journal of Atmospheric and Oceanic Technology,* 21, 730-741
[5] Thornes, J.E., Wood, L. & Blackmore, R. 1977. To salt or not to salt? *New Scientist*, 73, 326-328
[6] Thornes, J.E. Sugrue, G. & Osborne, R. 1983 Thermal mapping of road surface temperatures*, Physics in Technology*, 14, 212-213
[7] Thornes, J.E. 1991 Thermal Mapping and Road Weather Information Systems for Highway Engineers, In A.H. Perry & L.J. Symons (eds), Highway Meteorology, E&FN Spon, London, 39-67
[8] Thornes, J.E. 2000 Road Salting: An International Cost/Benefit Review*, Proceedings of the 8th World Salt Symposium*, Elsevier, Amsterdam, 787 –792
[9] Thornes, J.E. 2005 Snow and Road Chaos in Birmingham January 28th 2004, *Weather*, *60, 146-149*

Salting Route ID	**Typical Minimum Temperature (°C):**	**Treatment to be completed by:**
6	-0.5	1700h
8	-1.4	2000h
9	-0.7	2000h
3	-0.1	2300h
4	-0.1	2300h
7	-0.1	0400h
1	0	dry
11	0	dry
2	0.2	n/a
5	0.3	n/a
10	1.2	n/a

Table 1 Example XRWIS action summary (Example used is visualised in Figure 2d).

Site Forecasts	**Rundlestone**	**RD&E**	**Exton Camp**	**Little Stone**	**Haldon Hill**	**Cadbury Cross**	**Craze Lowman**	**Ashmill**	**Mean**
Number of nights	151	152	147	152	147	148	152	144	149
Percent correct	89.4%	91.4%	94.6%	88.8%	91.2%	91.2%	88.8%	82.6%	90%
Bias	0.85	1.73	1.16	1.85	1.12	0.97	0.82	1.6	1.3
Miss Rate	0.23	0.07	0.09	0	0.2	0.2	0.32	0.06	0.15
False Alarm Rate	0.04	0.09	0.05	0.13	0.07	0.05	0.04	0.21	0.09
Pierce Skill Score	0.73	0.84	0.86	0.87	0.73	0.75	0.64	0.73	0.76

Table 2 A summary of forecast quality for each site using the 1200 forecast run

Typical Forecasts	**Rundlestone**	**RD&E**	**Exton Camp**	**Little Stone**	**Haldon Hill**	**Cadbury Cross**	**Craze Lowman**	**Ashmill**	**Mean**
Number of nights	121	121	121	121	121	121	121	121	121
Percent correct	80.0%	88.4%	88.3%	90.0%	90.1%	89.3%	86.0%	85.1%	87%
Bias	0.51	1.56	1.26	1.65	1.08	0.85	0.97	0.76	1.1
Miss Rate	0.49	0.125	0.17	0	0.17	0.14	0.24	0.38	0.21
False Alarm Rate	0.01	0.11	0.1	0.13	0.07	0.05	0.1	0.06	0.08
Pierce Skill Score	0.50	0.77	0.73	0.87	0.76	0.81	0.66	0.56	0.71

Table 3 A summary of forecast quality Typical forecasts using the 0600 forecast run

Compile Geographical Database of Existing Salting Route Network

Parameter	Data Source
Altitude	TGS / DEM
Aspect	DEM
Landuse	VDP / LA
Latitude	TGS
Longitude	TGS
Road Construction	VDP / LA
Slope	DEM
Sky-View Factor	TGS
Thermal Singularity Survey	TGS / LA
Traffic	LA

TGS = Thermal Geomatic Survey
DEM = Digital Elevation Model
VDP = Vector Data Product
LA = Local Authority

Set-up GIS with Salting Routes and Outstation Locations

- Allocate virtual outstations to salting routes with no outstation

Set-up Secure Internet Site

- Visualisation strategy for route-based forecasts
- Set-up salting decision algorithms

Run IceMiser each night and display results on the internet

- Interrogate outstations to get noon data to initialise energy balance model
- Select appropiate Mesoscale Model output cell for each route
- Calculate minimum temperatures and surface conditiosn for each route
- Display visualisation of each route:
    - Red: Time of salting; Quantity of salt
    - Amber: Standby
    - Green: No action required
- Display visualisations of entire network:
    - Hourly forecast road temperatures
    - Hourly surface condition forecasts
    - Forecast graphs for every survey point and outstation
- Update forecasts as required throughout the day

Annual review

- Verify forecasts using outstation data
- Rerank / Redesign salting routes to optimise savings

Figure 1 *Flow diagram showing the procedure in developing XRWIS*

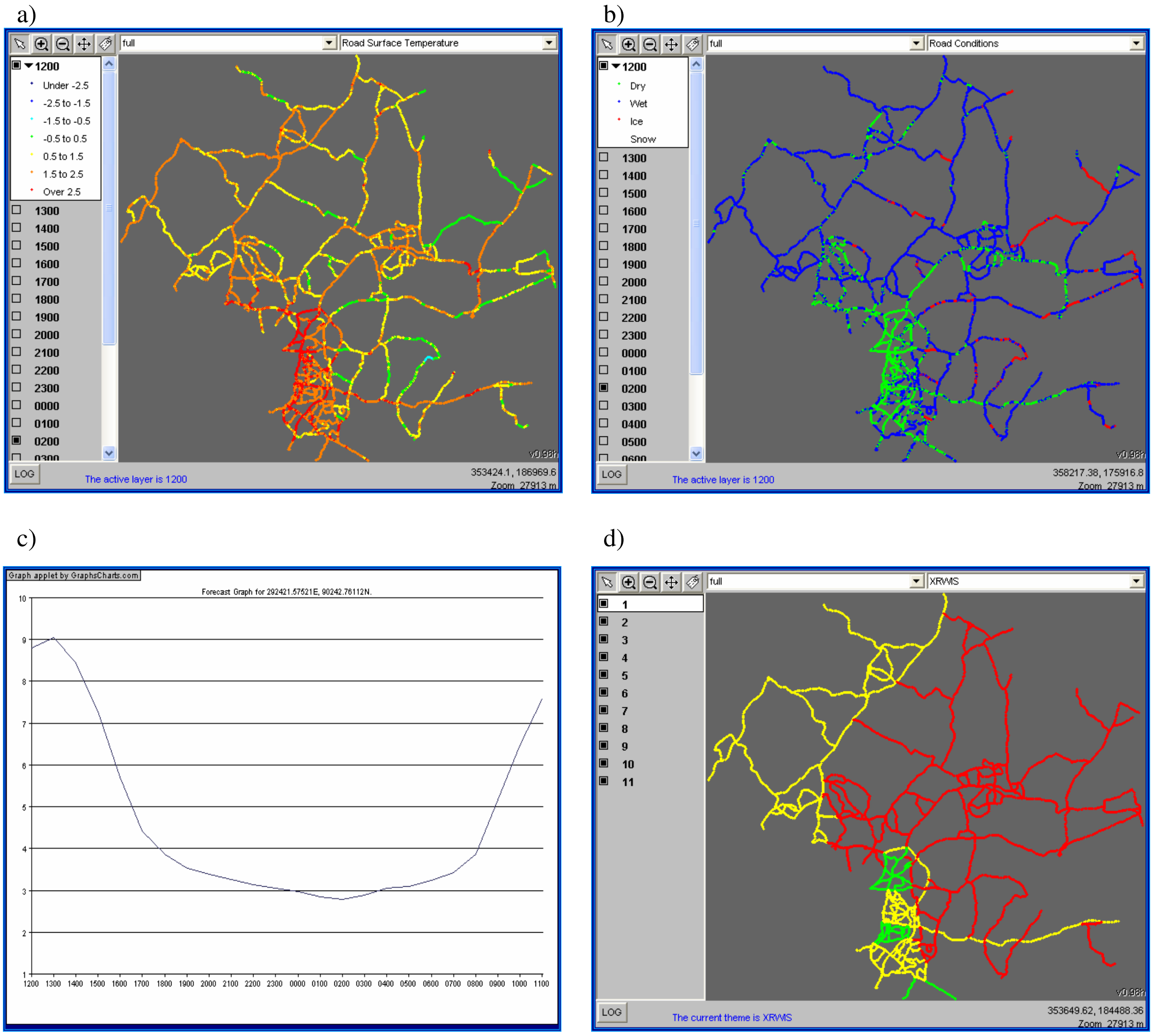

Figure 2 Conceptual visualisation of the new XRWIS paradigm showing a) Road Surface Temperatures, b) Road surface Conditions, c) Forecast Graph and d) ‘Traffic light’ salting routes.