QUALIFIED THERMAL MAPPING IN CASTILLA-LEÓN, SPAIN.

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ABSTRACT

One of the most critical issues in road management is the treatments provided to prevent ice formation on the road surface. One of the many techniques employed to optimize the application of these treatments is the creation of thermal road maps. Thermal mapping provides a “thermal fingerprint” of a road, identifying stretches of road that, under different conditions, remain abnormally cold or abnormally warm. This information can highlight potential trouble spots and, with the right equipment and weather predictions, even be used to produce predictions regarding the future state of road conditions.

Models such as that are successful in finding ways to alert road managers as to the spots along the road where ice or snow accumulation may occur. They are not so, however in interpreting how risky this will be to the user, based on the characteristics of the road. Ice formation, for instance, is always a risk, but less so in a straight road along a plain than in a curve overlooking a cliff.

In the N601 road in Valladolid, Spain, a pilot project was created to include other categories of factors related to driving risks in an application that is based on known thermal mapping techniques. These “road safety factors” are taken into account in providing the road managers with suggestions of areas they should prioritize in the anti icing treatments. These factors include variables such as road friction measurements in dry conditions, crossfall, alignment, collision obstacles near the road, areas lacking safety barrier, high embankments, traffic density etc. Each is weighed independently and a coefficient is produced that, applied to the icing potential prediction based on thermal mapping, provides managers with an automated system alerting them to trouble spots.

INTRODUCTION

One of the greatest conceptual shifts in winter road maintenance throughout the last couple of decades has been the change from favoring “reactive” strategies against adverse weather conditions to a preference for preventive strategies. The change, in other words, from removing and melting snow when it falls, to preparing the road to withstand some adverse weather, diminishing the accumulation of the snow and ice that will later need to be removed.

As these strategies have become the standard, more precise and evolved tools have appeared to aid in the planning of ice and snow prevention, allowing road managers to decide what likelihood exists of future problems, what moment is the ideal one to deploy preventive means or what precise areas of a road are most likely to be affected.

Thermal mapping is one such tool. Thermal maps are produced using geographical data, physical data of the road and statistical information. By thermally mapping a road, we can see how different points of the road vary in temperature with respect to a reference point along it, allowing us to identify which areas have a tendency to be warmer or colder than this predefined point. Then, simply by having the temperature monitored at one point, we can project it on to the whole stretch and spot “cold” and “hot” areas.

Since the 1990´s the techniques used for elaborating thermal maps have evolved greatly, and different factors have been added to better forecast the thermal behavior of the road: latitude, slopes, optical depth, emissivity, roughness, “sky view” factor, etc. These techniques, in other words, are extremely evolved and precise, with a sizeable amount of literature and empirical proof to back them.

If this is combined with precise weather prediction and a road surface temperature prediction model, then very useful and precise tools can be produced that will alert road managers in advance of areas likely to experience hoar frost, melting of snow that may re-freeze into ice or snow accumulation. A good example of this, for instance, can be found in Delannoy et al’s excellent paper on their Night Icing Potential project, presented at the 2008 Annual conference of the Transportation Association of Canada [4]

As useful a tool as this may be, however, it only supplies information regarding the potential for certain areas to ice over. A road manager must consider many other factors in maintaining the road safe. Is it a bigger risk to leave a “warmer” curve with a high longitudinal slope in a mountainous environment with no safety barrier untreated than to do so with a “cold” protected straight segment? Should an old road segment that is potentially iced be treated before a newer road segment with less worn tarmac? A segment with high traffic volume or a less transited one?

In a pilot project at the N-601 road in Valladolid (Castile-León, Central Spain), a pilot project was set up by road maintenance contractor Alvac to attempt to integrate these concerns within a weather/road state prediction tool. The basic idea was to “qualify” the output of a thermal map-based prediction tool with a risk assessment of the actual road and its immediate vicinity.

In essence, weather predictions are combined with road weather predictions to see where ice formation or snow accumulation is likely. This info is then combined with road risk analysis of a number of points along the road, to highlight especially troublesome areas. This process therefore “fine-tunes” road weather predictions, by incorporating road safety within the results. Let us now take an in-depth look at each of the elements being combined here, (1) thermal mapping, (2)local weather prediction and (3)road safety factors.

1. THERMAL MAPPING

1.1. Introduction

Since the eighties, a number of different alternatives for road surface temperature forecasting have been presented all over the world: Nova Scotia, Canada [4]; Japan [8]; Washington, USA [2]; Denmark [7]; Greece [3]; Wallonia, Belgium [5]; etc. In these case studies, the length of the roadway sections vary from a 140km highway [2] to 20km [8] and the altitude from sea level [4] to 800m [3]. Although the conditions are quite different, all the studies follow the same general forecasting framework, grounded on the so-called thermal fingerprint, which is the graphical representation of road temperature versus distance for a particular route. Usually, a thermal fingerprint is calculated for each particular characteristic weather situation (or Weather Type, WTs). The resulting thermal fingerprint is later used to project locally on the road (e.g. at a 1km resolution) the temperature forecasts issued from the existing meteorological station/stations characterizing homogeneous road segments. The number of meteorological stations along the studied roadway is also variable among the different case studies, from one/two stations [4], [9] to ten [2].

Our study analyzes a 50km stretch of road (N-601) with elevations ranging from 799 to 697 (see Figure 1). Only one meteorological station is available along the route measuring air temperature, humidity and wind speed (to identify the different weather situations) and road temperature, to be used (in conjunction with weather prediction data) to produce road temperature forecasts through METRo.

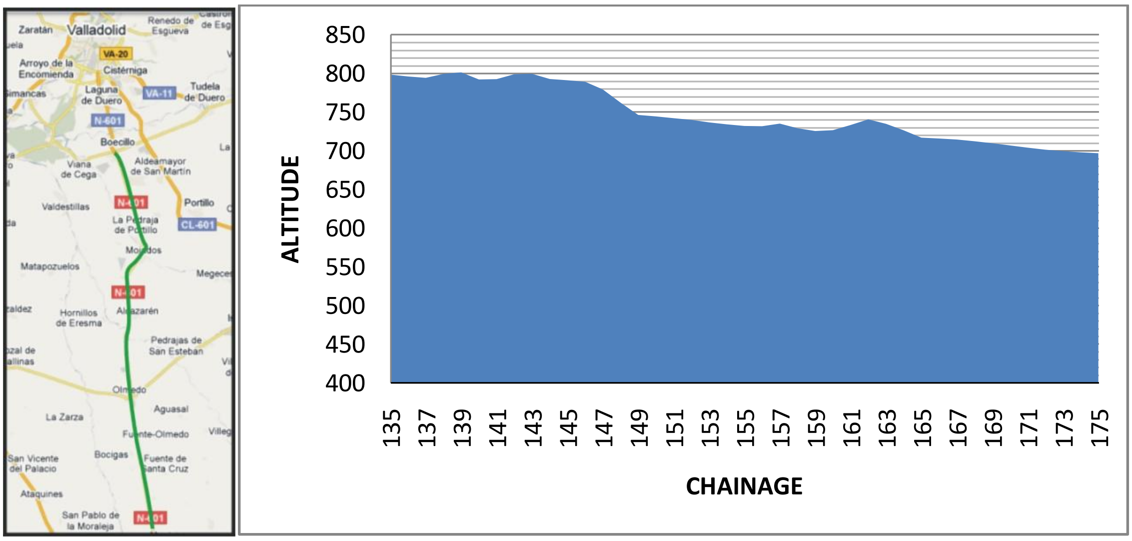

Figure 1 –N601 Valladolid Location and Altitude profile

1.2. OBTAINING THE THERMAL FINGERPRINT

Thermal mapping is a process by which the spatial variation of road surface temperature is measured, using a high resolution infrared thermometer. The road measurements are carried out at least once a day (in both road directions for the case of highways, as in [8]). In general, the studies focus on night time and measurements are performed close to the time when minimum daily temperatures are present (e.g. 07 UTC). There is no agreement according to the measurement step, i.e., the distance between one measurement and the following one; for instance, [3] take measurements every 10m, while [7] do it every 100m. Besides, the number of available day measurements to obtain the thermal fingerprint is also very different, ranging from 3 days [3], through 23 days [4], and up to 438 days [2].

In our study we have considered twice-daily measurements every 200m on the road, at 07UTC and 13UTC, in order to characterize the daily cycle and to provide a continuous risk assessment on the road. These measurements allow characterizing the thermal fingerprint of the road with a 1km resolution, providing also an estimation of the intra-segment thermal variability (which was used to control heterogeneities in the road segments).
In this case, road surface temperature measurements were taken for 20 days.
The general procedure used to obtain the thermal fingerprint from these road measurements is described in the following (see [4] for more details):

1. **1.** Configuration: Define the resolution for the thermal fingerprint (e.g. 1km) and the corresponding control points on the road, from the initial to the final one.
2. **2.** Alignment of the data: Since measurements do not fall at the same point in every run, a criterion should be taken in order to determine which measurement should be assigned to each control point in the route.
3. **3.** Calculate the differences of road temperature for each measurement point in each run $\mathbf{D_{ri} = T_{ri} - T_r}$, where T_{ri} is the road temperature at control point i for run r and T_r is the mean temperature of the road a particular run.
4. **4.** Define a number of weather types characterizing the different weather conditions affecting the road, and assign each of the runs to each particular weather type (that occurring the run day).
5. **5.** Calculate the mean thermal fingerprint curve for each weather type as the mean of D_{ri} for those runs are associated with the weather type. Then, the practical application of the thermal fingerprint for temperature road forecasting requires dividing the route into homogeneous segments, associating each of them to each weather station along the route.

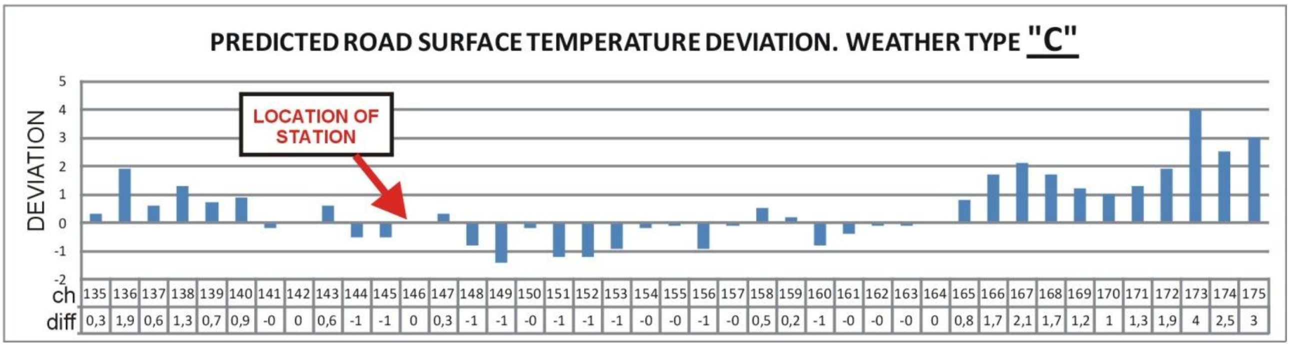

Figure 2 – Example of thermal fingerprint

1.3. WEATHER TYPES FOR FINGERPRINTING

Step 4 is in the above scheme is a critical point of this process, since there are many ways to classify the weather situations according to the available information [1] (see Anderberg, 1973, for an overview on classification techniques). Several authors, used a simple classification in three weather types: extreme, intermediate and damped, based on cloud cover and wind speed [4]. Other authors, performed a classification following Pasquill's Stability Classes, which focuses on atmospheric stability [8]; others preferred using an objective classifications based on standard statistical methods such as k-means [6] or hierarchical techniques [9]. The k-means algorithm is very popular among the objective classification techniques, because it is very easy to use and it is also efficient. This algorithm gathers n elements in k classes, where k is known a priori. Each class is represented by the mean of its members, which is called centroid. K-means starts from an aleatory classification and aims to minimize the intra-classes distance. There are different criteria to calculate this distance; one of the most common ones is the standard deviation inside each class.
In this project we use a modification of the k-means algorithm (Self-Organizing Maps, SOM), which allows for a topographical arrangement of the resulting weather types in a two-dimensional lattice, so similar weather types are displayed closed together in the lattice. This topographical arrangement has many interesting applications for visualization purposes.

To obtain the weather types, we classify the weather situations applying the SOM algorithm with 9 and 16 centroids, respectively, in order to test the sensitivity of the results.

The weather state is defined considering the temperature, humidity and wind fields from the WRF model over the region of interest (a 81x81 km grid centered on the road, with 9km resolution; i.e. a 9x9 pixel map). The similarity between two different atmospheric states is defined as the mean difference of the corresponding ”thermal fingerprints"; thus, classification of weather states is driven by road thermal fingerprint similarity and not by weather similarity.

2. ATMOSPHERIC/WEATHER PREDICTION

Local weather forecast is one of the most challenging problems in operational meteorology from both a scientific and socioeconomic standpoint. Downscaling methods work by post processing the outputs of global atmospheric numerical models (for instance, the ECMWF or the GFS models) using regional atmospheric models adapted to the region of interest (in this work a 100x100 km domain covering the region under study). In this work we use the WRF-UC Iberia 9km simulations done with the open-source WRF (Weather Research and Forecast) model developed by NCAR and by the Meteorology group in University of Cantabria (in particular WRF-ARW 3.1.1 version). In order to simulate this final domain with a 9km resolution, we run two nested grids at 27 and 9 km, for a small North-Atlantic region and the Iberian Peninsular domains shown below. For each run, a total of 108 hours are simulated daily, from 12 UTC of day+0 to 00 UTC of day+4. The projection used is a Lambert Conformal conic projection. The results are obtained daily for a 9km grid covering the region under study (see figure 3); moreover, a linear interpolation of the results to the local position of the meteorological station is also produced in order to provide the prediction of the air conditions corresponding to the location of the meteorological station.
Figure 3 shows the meteogram corresponding to the selected location, showing the ensemble of five physical parameterizations of the model used for the study and comparing the results with those obtained from the HIRLAM 16km model from AEMET (see http://www.meteo.unican.es/localForecast for more details).

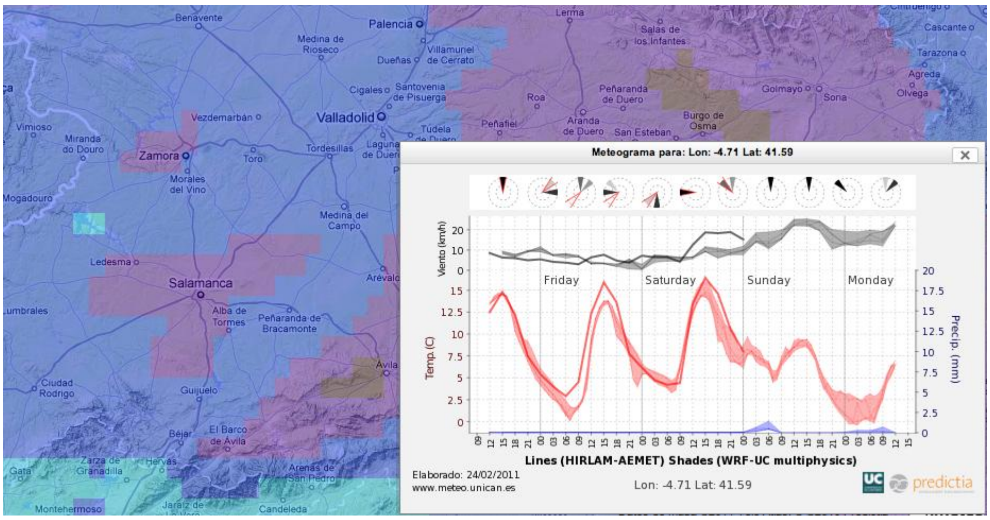

Figure 3 – Regional meteogram

3. ROAD SAFETY FACTORS

3.1. Road Description

The road is the N601 in Valladolid, from the Segovia province limit in chainage 135 to Boecillo, chainage 175. It is a single carriageway, with two 3.5m lanes and a 2m hard shoulder.
The road is in the Castilian Plateau, with cold winters and high winter maintenance requirements. The road has a South-North direction. It has several access tracks. The most problematic intersections are managed with light signals/semaphores.
The alignment is mostly straight, with long radius curves. The slip roads have sufficient length, compliant with Spanish specifications.
The average daily traffic varies between 4700 vehicles at the south end to 11000 at the north end of the sector (closer to the regional capital of Valladolid).

Figure 4 – N601

3.2. Road Safety indicators

In order to include factors related to the road safety for each kilometre, a methodology had to be chosen. Nowadays, safety indicators are considered to be objective tools that offer great information about the real condition of the road infrastructure. There are numerous methods and procedures to produce road safety indicators. Given that the purpose of the tool is to provide information to help the maintenance managers decide their anti-icing strategies, the indicators used should be simple enough for them to understand easily. Also, the output of the temperature part of the tool is a discreet number of figures, typically ranging from -4 to +6 degrees Celsius. The road safety risk factors should be also a discreet number of "ratings" in order to merge with the meteorological part. The "Stars" rating used in EuroRAP´s RPS method was decided to be the ideal indicator for the tool.

3.3. Road Protection Score (RPS) Method

The European consortium EuroRAP, produced the RPS (Road protection score).
Following the inspections of the road infrastructure elements, a Road Protection Score (RPS) is calculated for each 100 metre section of road. The RPS is an objective measure of the likelihood of a crash occurring and its severity, based on an assessment of a road's infrastructure elements. The RPS forms the basis for generating the Star Ratings. The RPS describes the protection from accidents that a road provides (elements of primary safety) and the protection from injury when collisions do occur (secondary safety). RPS star number relates to this by using tables and algorithms to award a certain number of stars depending on how "safe" a road is.

3.3.1. *Crash likelihood factors*.

These factors deal with how well equipped the road is to prevent accidents. Elements like traffic signs, linear marking, alignment, etc can, if used correctly, reduce the chances of accidents occurring. The RPS assesses elements such as the example below:

Delineation	Relative Risk
Adequate	1.00
Poor	1.20

Figure 5 – Example: RPS factor. Source: IRap.net

3.3.2. *Crash severity factors*.

These factors deal with how forgiving the road is when an accident occurs. For example, the existence of a safety barrier when the road is on a steep embankment may reduce the injuries in case of an accident.

Figure 6 – Examples of abscence and presence of Safety barrier on the N601

The RPS assesses elements like the example below:

Category	Risk Factor
Safety barrier	1.75
Distance to rigid object 5-10m	3.80
Deep drainage ditches and steep embankments	5.00
Cliff	10.00

Figure 7 – Example: RPS factor. Source: IRap.net

And the total list of elements taken into account is:

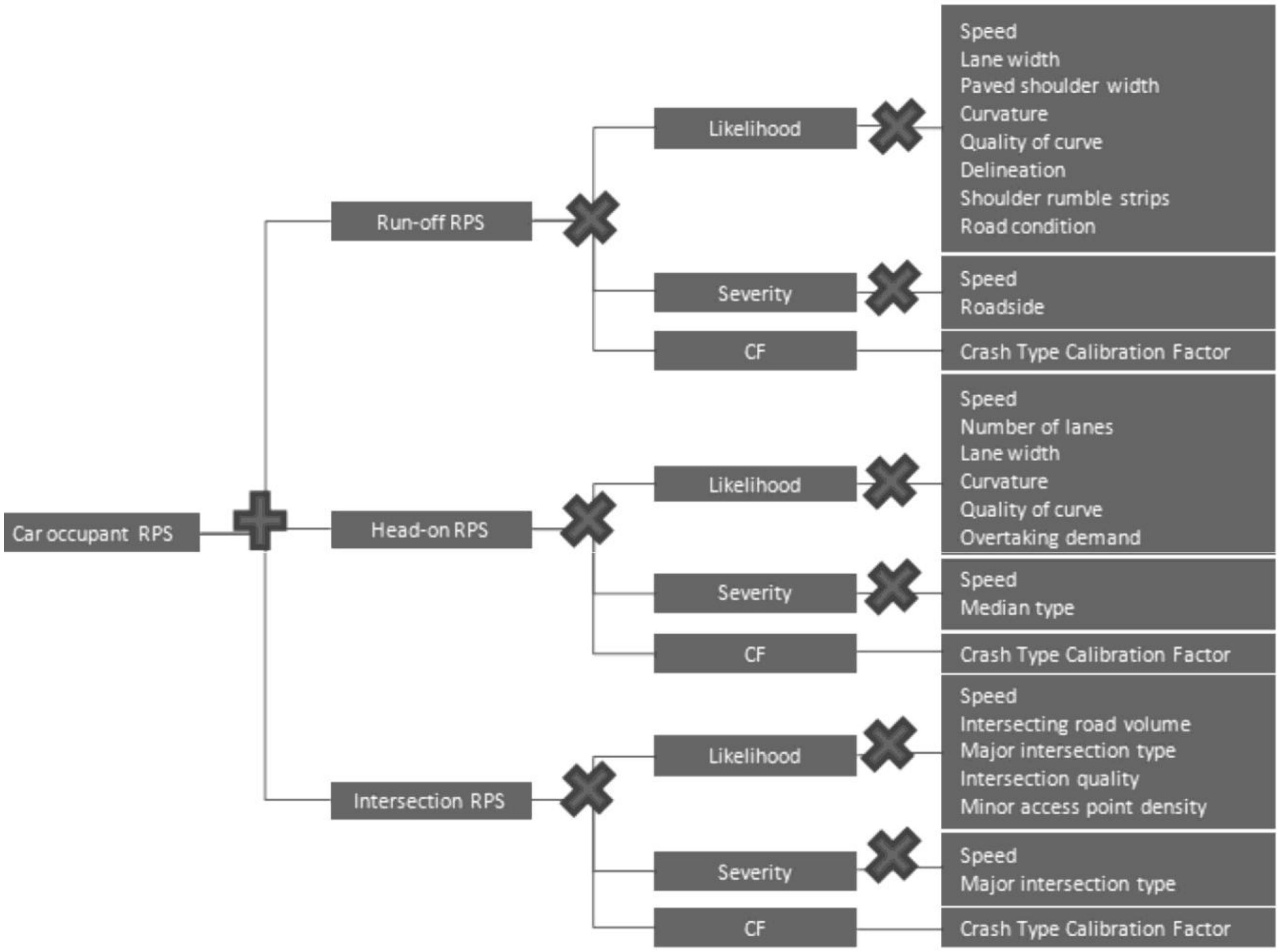

Figure 8 – Example: RPS for car occupants

With all the elements assessed, a Star Rating is produced. As explained above, the road is analysed in 100 m segments. Thus, for the length of the road the star rating will vary.

The resolution of the road temperature part of the tool was defined to be 1km. So the same resolution had to be used for road safety ratings. Every Km was averaged and given a star rating.

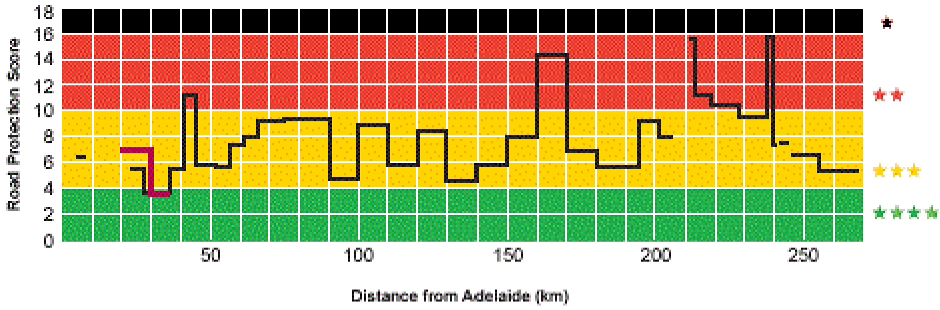

Figure 8 – Example: RPS Star rating chart. Source: Ausrap.org

3.4. Integration of safety Factors

The forecasts this tool produces are used for tactical and strategic decision making. Its output is temperatures. A method to simplify the information given to the maintenance managers is to "subtract" a certain amount from the forecast temperature value depending on the "risk" obtained for every kilometer. This way a new safety factor is introduced: by subtracting a certain value to the forecasted temperature, the forecast has a bigger

probability of being on the safe (colder, and therefore more likely to be pre-emptively treated) side of the real temperature.
The idea behind including the information this way is so there is no extra data given to the decision-maker, so no complexity is added to his job or to the display in the tool.

With this idea in mind, a decision had to be made regarding how much "weight" in terms of degrees should be given to the risk index. The values shown on Figure 9 show what is "subtracted" from each km`s road surface temperature prediction depending on its star rating.

Figure 9 – Values to be substracted to the Road surface temperature prediction.

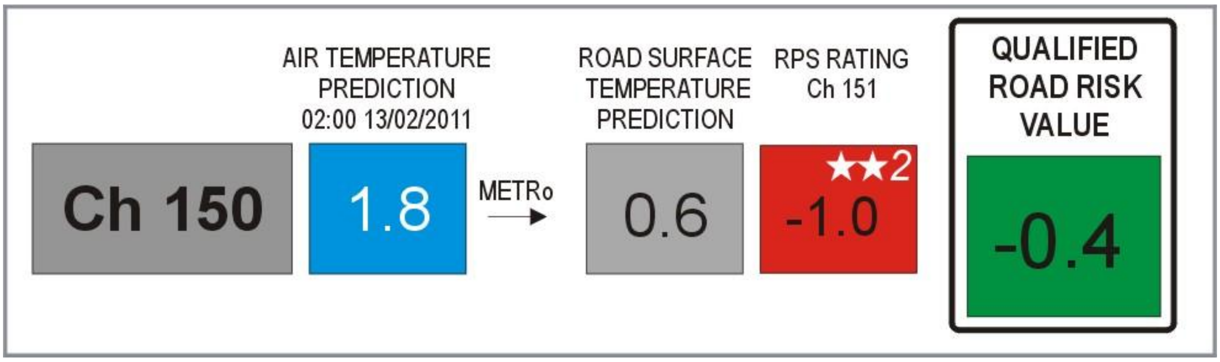

Figure 10 – Example of integration of star rating in N601 Ch 151. Figures in Celsius.

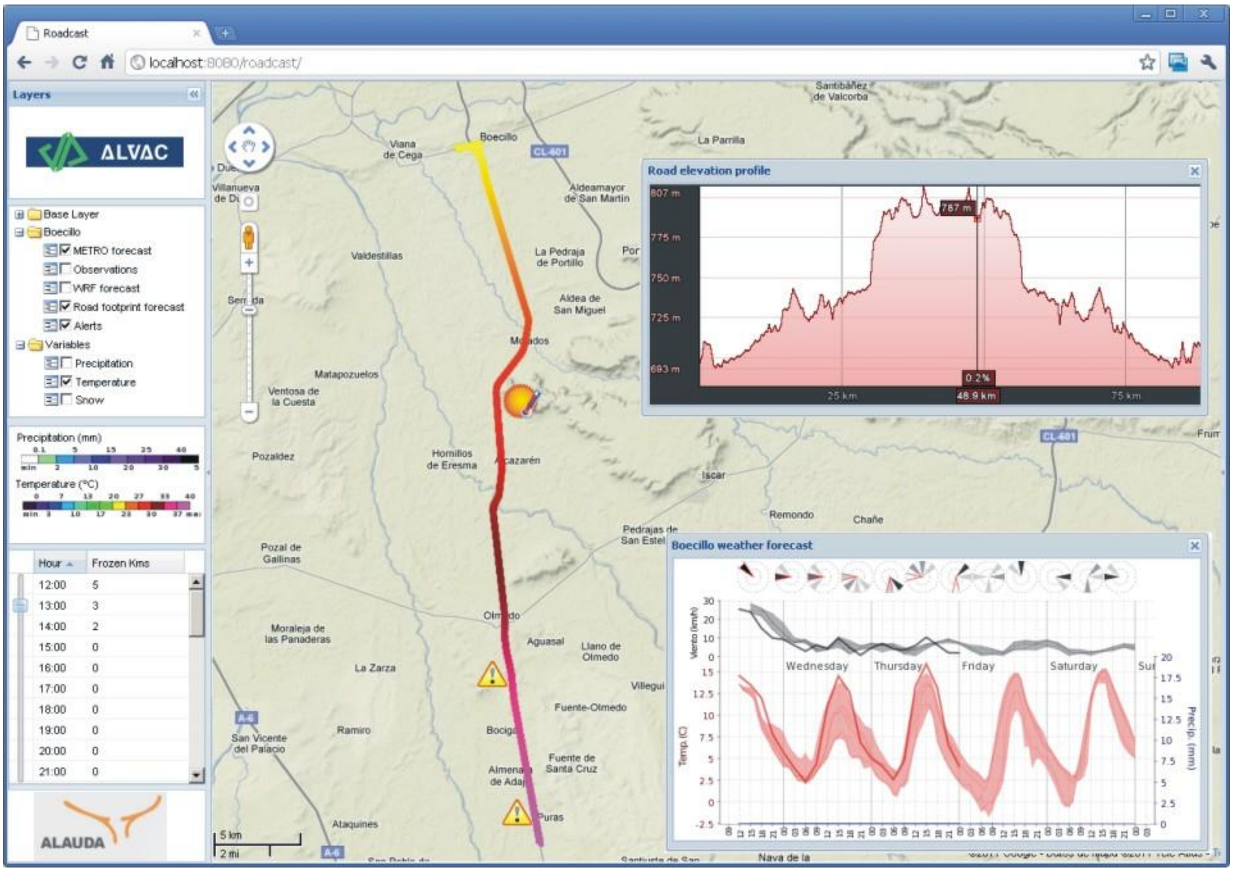

Figure 11 – Display of qualified thermal mapping tool.

4. PRELIMINARY CONCLUSIONS, LESSONS LEARNT & FUTURE CONSIDERATIONS

Pending verification and fine-tuning of the system (to be undertaken during the following months and especially, over the next winter season), road managers on the N601 have found it to be a useful tool both for preparations for an incoming storm (strategic decision-making) and as decision support tool when combating adverse meteorology (tactical decision-making). The benefits of more relevant and accurate forecasts, combined with the alerts regarding trouble spots and heightened risk areas allowed them to allocate resources more effectively and with more confidence. These results, by themselves, have been encouraging enough for the company to proceed to map the whole of the network, work on which will be completed and integrated into the display by the beginning of the 2011-2012 winter season.

One especially fruitful aspect of the project derived from the close involvement of the road managers themselves, and the adaption of the tools to their actual needs, as expressed by them. One clear example of this was the development of the application's display, which evolved greatly in response to road manager suggestions. Faced with high-risk, high stress and pressured decision making during storms, the road managers suggested the simplification of the display and of the information output. Originally, detailed explanations on the reasons for areas to be considered "high-priority" were immediately available on the user interface, but were gradually reduced. This resulted in a more intuitive display that aided users to rapidly grasp a global picture of the situation, simplified information processing and allowed for “snap decision-making” in high-stress situations.

The decision whether to employ the “complex” or “simplified” display will, however, largely depend on the manager’s work habits and personal preferences. If there is one thing that we have learnt as a road maintenance company it is that the tools must adapt to the road manager, never the opposite. Therefore, the most elegant solution to the problem will probably be to create three layers to the display: (1) weather+road, (2) road protection score alerts and (3) integrated layer using the “temperature subtraction” method. This way, measured and long–term planning could be performed with layers 1 and 2, whereas “in the moment” reactions could be taken with the integrated display.

Another important factor to discuss is the method employed to define the “high risk” areas of the road. Although the Road Safety Protection Score is ideal in that it is a numerical method based on objective, observable data, it does have the downside of being somewhat laborious to produce. After all, 28 factors must be analyzed per 100 meters of road to come to a score. If this work is undertaken by the road maintenance company, then it can be done at little cost, since qualified workers already on the payroll and on the site can be employed to collate the information. If an outside contractor were to undertake the work, however, it is a time-consuming and toilsome effort that would surely result in a considerably higher expense.

This problem can be side-stepped in two ways. First, over the course of the study, we have found driver associations to be a priceless source of information regarding road safety. In Spain, in particular, two of the main associations, the RACE and RACC (Real Automóbil Club de España and Real Automóbil Club de Cataluña, respectively) regularly produce road safety reports using EuroRAP methods. Although, of course, not every road is supervised by these bodies and, also, the detailed analysis (of 100m stretches) cannot always be made available to the public, a large amount of good quality data with which to “qualify” predictions can be gleaned from them.

A second method would simply be to use accident report data as the “qualifying” factor. A full set of accident reports over a span of three or four years can paint an accurate picture of what sections of the road are more likely to witness accidents (presence/absence of accidents, number of accidents per 1km stretch), what type of accidents (collision, run-off from road), the climatic conditions in which they happened (dry, wet, snow, low or high visibility) and their severity (no personal consequences, slight or severe injuries, fatalities). This data set is easier both to obtain and to process, and may produce very similar results (it is, in fact, the data set employed for other EuroRAP indicators), probably making it the way forward if simplification of the tool is deemed an asset. The authors of the project plan to create this new risk factor in preparation for the winter season, and run it in parallel to the original model to see if differences, if any, can be observed in the resulting predictions.

Another avenue for improvement would come from increased verification and correction capacity of the model in real time, in other words, an increased access to meteorological and road temperature data. In this respect, the deployment of mobile weather stations and super vision vehicles whose data automatically corrects biases in the prediction would greatly improve its reliability. Due to questions of cost and ease of actual deployment, though, it is still unclear whether this would be advisable: firstly, one of the main assets of this system is its low cost, and costly additions must be studied with care; secondly it is unlikely that road managers will be able to spare manpower and vehicles for “meteorological supervision” during adverse weather episodes.

Low cost road weather information stations is another of the possible ways forward. A number of basic model weather stations, supplying merely road temperature, air temperature and humidity could conceivably be employed to verify and correct predictions in real time. Although, in this case, the manpower and actual availability during crises disappears, the same concern regarding cost applies. The authors of the project are also looking into developing such an alternative, but, as of the moment of drafting this paper, had not yet found a system that was both reliable and inexpensive enough to be deployed.

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