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Automated winter road management procedures: an entry gate for advanced its deployment?

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Abstract

This paper discusses the case of an ITS demonstrative deployment, which has been organized with the purpose to investigate the RWIS potential in the Autonomous Province of Trento (Italy) and to deepen the local environmental impacts associated winter road management activities. Early optimization margin studies have demonstrated that such potential is probably higher than what is experienced by other northern regions in which similar systems are traditionally more widespread. RWIS are in the condition to pave the way for the local deployment of automated winter road management schemes, and represent a valuable starting gate for the rapid deployment of cooperative and automated scenarios in alpine environments. Their effective local potential needs to be better confirmed; non-technical entry barriers and environmental aspects could play a key role in speeding up (or not) this deployment process.

Keywords: automated winter road management, cooperative systems, Road Weather Information Systems.

The path towards automated management

Intelligent transport systems (ITS) commonly refer to transportation systems in which a significant amount of technological intelligence has been placed in order to support human control and decision-making processes. In the past years traditional ITS, typically deployed as stand-alone systems, have managed to remarkably improve humans' cognitive and decision-making intelligence, i.e. their capability of (i) having knowledge about the current mobility and traffic conditions and (ii) efficiently and effectively developing reactive or proactive management actions in order to avoid or limit the negative externalities of certain network perturbation events. Cooperative ITS (C-ITS) promise to employ communication technologies in order on one side to enable a shared cognitive intelligence among all mobility agents (e.g. traffic management centers, travelers, vehicles, road operators), and on the other side to put the premises for novel decision-making processes' schemes, in which objectives are shared and agreed by all parties [1]. The final long-term perspective, to be enabled in particular by the consolidation of autonomous vehicles' technologies, is to have automated transportation systems supervised by humans, in which the equilibrium between mobility demand and offer is dynamically managed by guaranteeing high efficiency performances.

Winter road management as a possible C-ITS entry-point deployment scenario for alpine regions?

The path towards the operational deployment of such automated management schemes is however complex to be started in practice. An increasingly adopted methodology is to foster the migration from ITS to C-ITS by concentrating the efforts on application scenarios that are particularly suitable (and economically viable) for the geographical areas in which they are deployed. In alpine regions, a possible concrete application scenario could be winter road management. In this domain, ITS are typically defined as Road Weather Information Systems (RWIS) and provide operating authorities with helpful information in the decision making process about what action to take for preventing the appearance of ice or the accumulation of snow on roads [2]. Negative externalities of winter road management activities and RWIS benefits have been already well investigated by numerous previous research works, and are summarized in Table 1 [3-4]. Unfortunately the quantification of such optimization margins is strongly dependent on the geographical area under study, since they depend on its specific climate and weather conditions. Moreover, climate changes are responsible for unstable meteorological patterns, so a cost-benefit analysis applied for the long-term period must properly take in consideration such climatic trends.

Table 1: Winter road management issues and RWIS benefits.

Negative externality	RWIS benefits
Safety. Road traffic accidents directly attributed to skidding caused by unfavorable weather. Increased risk of accidents typically associated to a reduced number of fatal injuries (due to vehicles driven more slowly) but to an increased occurrence of minor accidents. Liability issues caused by suits between drivers and road operators.	• Areas with frequent snow storms and high road treatment need experience a -20% reduction in the number of accidents, -40% reduction in the number of fatalities and serious injuries. • Reduction of costs associated to accidents, fatalities and serious injuries, time lost due to accidents: in areas with about 60 weather events per year and one accident per weather event, the overall economical savings can be in the order of \$ 35 million. • RWIS can support road operators to

	demonstrate treatment activities done and road conditions during an accident in case of legal litigations.
Environment. Long-term and short-term impacts associated to the use of chemical de-icers (typically sodium chloride) to melt ice and snow: soil and water pollution, increase of particulate matter concentrations, alteration of vegetation ecosystem, water, roads and vehicles corrosion. Impact associated to stop-and-go traffic conditions caused by weather events.	• Reduction of pollution and corrosion phenomena associated to more effective salting activities. • Possibility to take into account road salt contribution in particulate matter levels. • Increased levels of service and reduced number of weather-related traffic congestion phenomena (and associated air pollution peaks).
Mobility. Increased journey times due to congested and/or closed roads, slow moving road treating vehicles.	• Improvements in traffic flows due to better road treatment actions during weather events. • Higher and more fluent traffic levels positively contribute to the process of snow and ice melting. • RWIS can suggest the exact road treatments timing in order to avoid that traffic disperse salting materials. • Estimated contribution are in the order of + 20 [mph] on highways, + 10% of traffic flows. In a $15 billion economy, RWIS could save over 5 million driving hours and produce economic savings of up $200 million.
Maintenance resources. High costs in terms of treatment material, maintenance vehicles, road operator staff.	• Treatment material and maintenance vehicles: reduction of treatments number (typically in the order of 30%) and associated salting resources and fuel consumption (savings in the order of 50%); maintenance costs of road operators vehicles reduced in the order of 25% . • Road operators: reduction of decision-making time (on average 2 hours per potential treatment), reduction of driving time (on average in the order of -50%), reduction of stress conditions (case studies show a reduction of up 75% of absences caused by stress).

Early RWIS potential assessment in the Autonomous Province of Trento

One of the objectives of the EU-funded project CLEAN-ROADS, supported by the LIFE+ program of the European Commission, is to investigate in which terms such RWIS potential can be applicable to an alpine region like the Autonomous Province of Trento, in the north of Italy, and to specifically quantify the environmental improvements that an advanced demonstrative ITS implementation can determine [5]. The Autonomous Province of Trento is one of the largest territories in Italy, with an extent of about 6,207 [km^2] and a regional road infrastructure extension of 2,445 [km]. The region is mainly a mountainous area, and temperatures can easily reach in the winter time, particularly in the valleys and reliefs in the north, values of -15, -20 [°C]. As far as snow precipitations are concerned, typical values are 100-180 [cm] per year over 1,300 [m] above sea level, 200 [cm] over 1,500 [m] and more than 400 [cm] over 2,000 [m], with a consequent effect on the duration of the snow on the ground, which can thus vary from 120 [days] to 150-170 [days].

First answers to these open questions were given by the results obtained in an ex-ante monitoring campaign that was organized during the winter season 2013-2014. An observation site was activated in correspondence of the locality Cadino, placed on the regional road SS12 connecting the Autonomous Provinces of Trento and Bolzano (Figure 1).

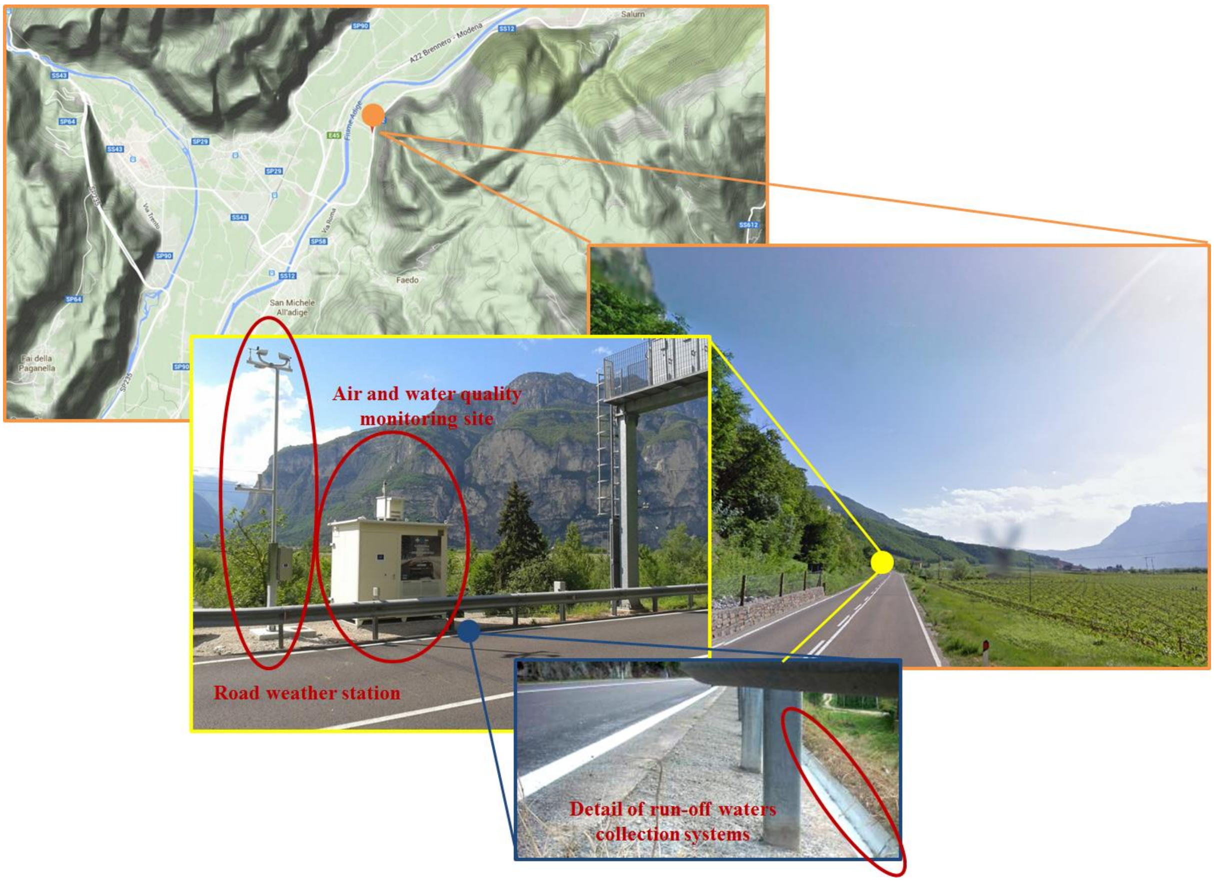


Figure 1: The observation site in locality Cadino.

The choice of this route for the pilot activities of the project was not casual, and is related to the initial hypothesis that the highest RWIS potential is more likely to be found at the valley bottoms and at lower altitudes, where the boundary between the decisions to carry out a treatment or not is much narrower. Cadino was selected not only for its facilities (e.g. power supply availability), but also because its position is particularly interesting in terms of geographical features such as topography and sky-view factor, that have a key role in the evolution of road surface temperature patterns. The observation site in Cadino is capable of monitoring on real-time data about (i) road surface (and sub-surface) conditions; (ii) weather conditions; (iii) traffic flows; (iv) air pollution (i.e. particulate matter) levels; and (v) run-off water streams chloride concentrations. These data were directly correlated with the data related to the road treatments carried out by the operators in charge of the maintenance activities on this route, automatically recorded thanks to a simple activities tracking system implemented as a smartphone application. Road treatments are currently not supported by any structured decision support system, and their necessity is primarily evaluated on top of the consolidated practical experience of road operators, together with available weather bulletins and weather data. Further correlation with accident data, collected by several sources and covering minor accidents as well, led furthermore to an assessment of the actual externalities related to road safety.

One of the most interesting results of this study is the comparison between the real treatments carried out by a selected team of road operators on a route stretch of about 16 [km] and the ones they should have been actually needed. The latter ones have been estimated by considering *a posteriori* the road weather data collected in the observation data in Cadino with a temporal resolution of 10 [minutes], as presented in Figure 2.

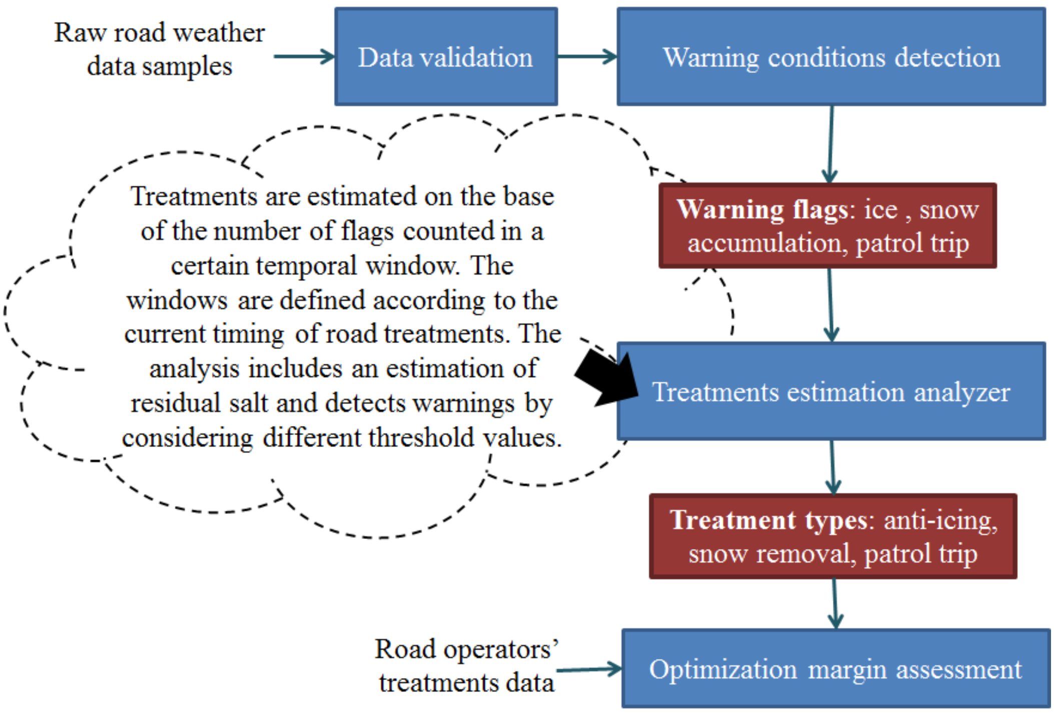


Figure 2: The workflow for the estimation of optimal road treatments.

The results of this study refer to winter season 2013/2014, which was characterized by exceptional meteorological conditions with frequent and intense precipitation but high temperatures, as presented in Figure 3. These meteorological patterns have significantly increased the level of uncertainty in which road operators had to work: roads were in most of the cases wet, and with temperatures in the range of 0 [°C].

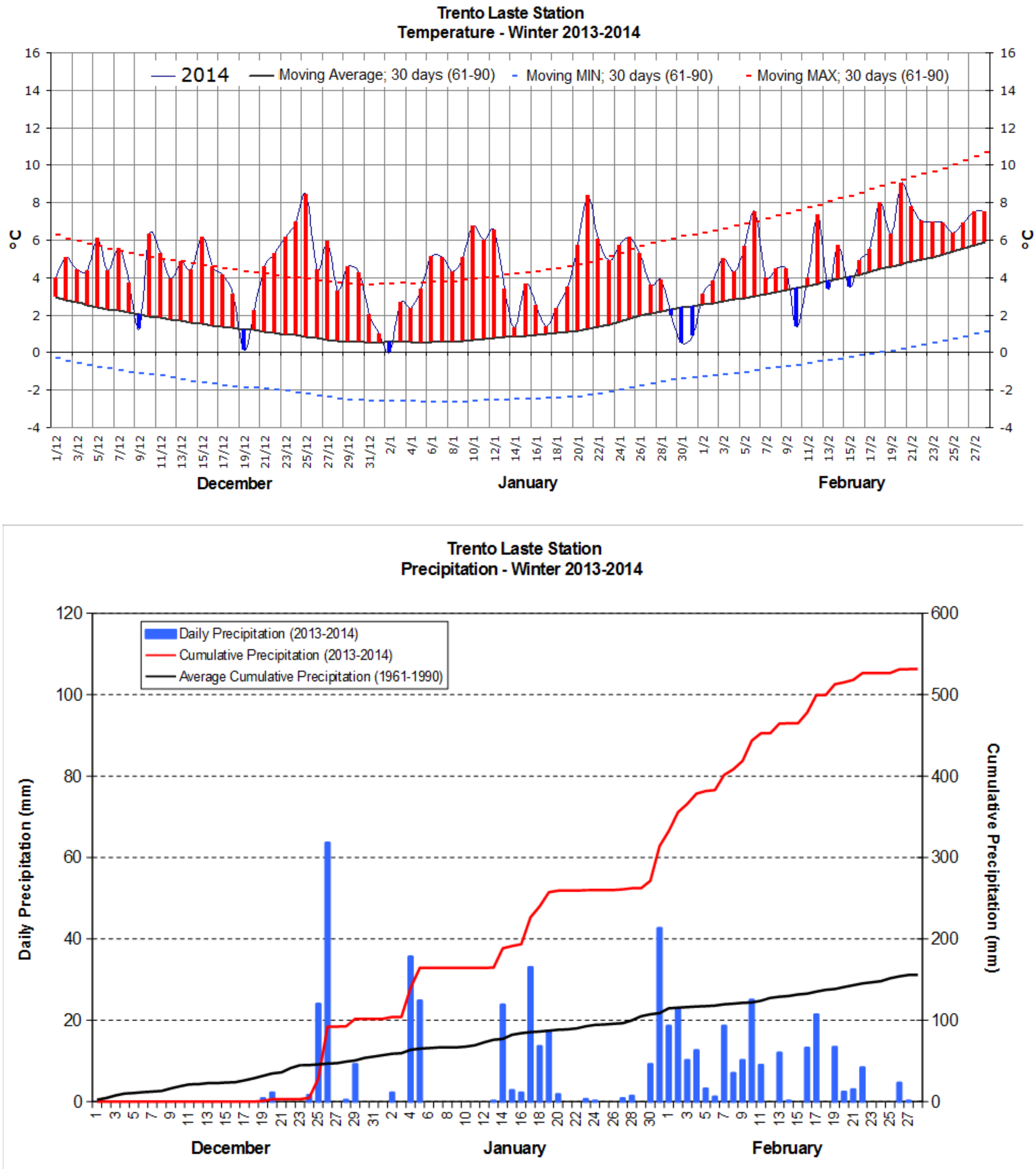


Figure 3: Exceptional meteorological conditions registered during the winter season 2013/2014: air temperature - (top) and precipitation data (bottom).

The treatments' estimation process takes into account patrol trips as well, which are associated to the current choice of road operators to decide in uncertain situations to directly examine the road conditions, and to apply localized treatments if needed (e.g. in correspondence of cold

hotspots). The resulting estimated road treatments represent the optimal case, since they are based on a quantified evaluation of what has happened in the previous temporal window under analysis. In practice, this information is not available, since forecast data (when available) are always affected by a certain degree of uncertainty. The calculated optimization margins therefore represent an upper bound of the benefits that one can achieve through an advanced RWIS, which is moreover amplified by the fact that a road treatment is induced in practice by the meteorological conditions evaluated over the whole controlled road stretch, and not only by what's happening on a single monitored point.
The results of this analysis show a greater potential for RWIS than the one suggested in the available literature and previously reported, as summarized in Table 2.

Table 2: Optimization margins preliminary results.

			Treatments observed					
			YES					NO
			Patrol trip	Anti-ice	Prev.snow	S. Remov.	TOTAL	
Treatments estimated	YES	Patrol trip	4				4	
		Anti-ice		4			4	
		Prev.snow			2		2	3
		S. Remov.			1	7	8	
		TOTAL					**18**	**3**
	NO		14	17	0	0	**31**	**230**

The final estimation in terms of maximum number of treatments that can be locally avoided is quantified for the winter season in the order of about 63%. If one takes in consideration patrol trips and anti-ice treatments only, this optimization margin is even higher, and can be estimated in the order of 79%: 31 of the 39 observed activities have been considered in fact as unnecessary. These impressive results are probably strongly amplified by the exceptional meteorological conditions registered: due to the higher level of uncertainty in which they had to work, road operators decided to further oversize the number of treatments in order to prevent any safety hazard. Psychological factors have played an important role as well, since operators are used to treat roads almost every day in normal winter seasons and the absence of "harsh" winter conditions have put them in frequent situations of stand-by and wait for the first road weather events, with the consequence of further overestimating possible potential dangers on roads.

The path towards automated procedures for winter road management

The ambition of the CLEAN-ROADS project is not only to put at a disposal to road operators an advanced Maintenance Decision Support System (MDSS) that can improve the efficiency of their treatment actions, but also to design and empirically test a set of internal automated procedures that can better organize winter road management activities overall, directly associated to different "layers" of forecasting tools (Figure 4).

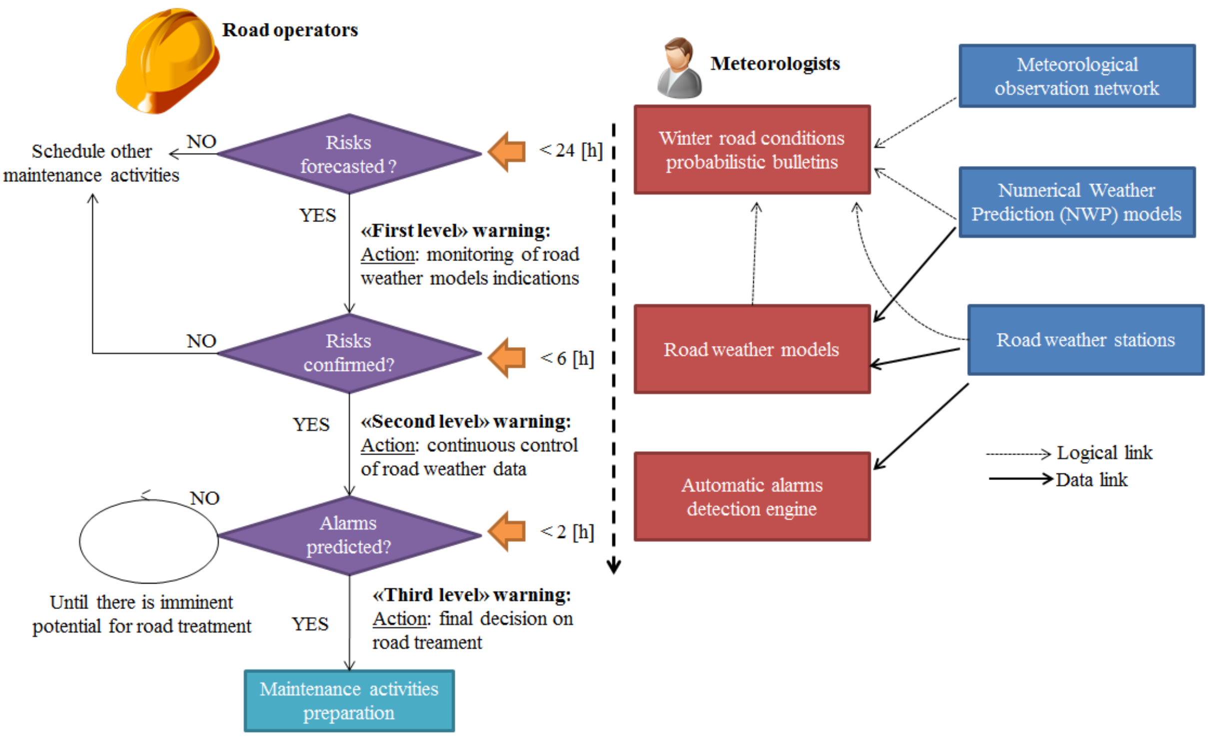
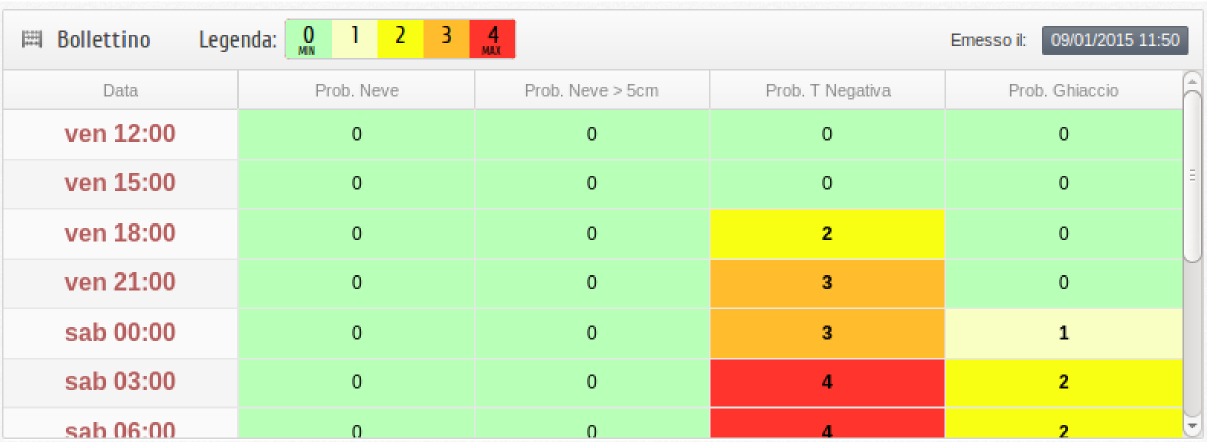


Figure 4: The reference approach for the introduction of automated winter road management procedures.

Probabilistic bulletins and "first level" warnings

The procedures are going to be activated as a function of the quantitative indications given in *ad-hoc* probabilistic bulletins that meteorologists of the Autonomous Province of Trento have been starting to prepare every day specifically for the winter road management sector after taking into properly account data, measurements and forecasts put at disposal mainly by the provincial meteorological observation network, the road weather stations as well as the numerical weather prediction (NWP) models such as ECMWF and COSMO and other road weather models. An example of bulletins is presented in Figure 5.


Bollettino Legenda: 0 MIN 1 2 3 4 MAX Emesso il: 09/01/2015 11:50

Data	Prob. Neve	Prob. Neve > 5cm	Prob. T Negativa	Prob. Ghiaccio
ven 12:00	0	0	0	0
ven 15:00	0	0	0	0
ven 18:00	0	0	2	0
ven 21:00	0	0	3	0
sab 00:00	0	0	3	1
sab 03:00	0	0	4	2
sab 06:00	0	0	4	2

Figure 5: Probabilistic bulletin example.

Four different events are covered: (i) snow event; (ii) heavy snow event with accumulation greater than 5 [cm], (iii) negative air temperatures and (iv) ice on road. Probabilities are expressed on three-hours steps according to four different levels: (i) level 0, which is associated to a less-than-1% probability (extremely unlikely event), (ii) level 1, which indicates 1-5% probability (unlikely event), (iii) level 2, which indicates 5-30% probability (possible event – less likely than not), (iv) level 3, which indicates 30-60% probability (probable event – more likely than not) and (iv) level 4, which is associated to a greater-than-60% probability (very likely event). Probabilistic predictions are defined on top of minimum risk criteria: the objective of this first forecast stage is to minimize not the overall prediction error but the number of missed treatments, which can determine incalculable safety costs. For this reason, the absence of risks is forecasted only in case the meteorological evolution is sufficiently stable and deterministic to guarantee the possibility to allocate the road maintenance resources for other scheduled activities.

Road weather models and "second level" warnings

The second stage of warning is associated to the outputs of selected road weather models, which can be typically run more than once a day and can provide an updated nowcast projection of the potential risks on roads due to weather. The vision is to have at this level a spatialized prediction model (XRWIS) that can geographically represent the road sections with predicted risky conditions.

Real-time alarms and "third level" warnings

In case such risks are effectively confirmed, road operators enter in the third and last warning stage which is characterized by a continuous control of the road weather data provided by the road monitoring network. The final decision and calibration of road treatment activities is finally taken when specific alarms associated to a lowering of road friction conditions are generated. Alarms are not only going to be based on real-time measurements, but also take into account nowcasts calculated on the very short period (i.e. on a time horizon of less than two hours) on top of different approaches such as the persistency and worst-case ground surface temperature cooling trends. In this way, proactive actions can be more efficiently enabled and the timing for treatments more wisely selected.

The architecture of the CLEAN-ROADS system and its possible evolution towards C-ITS and automated systems

During the winter season 2014-2015 this automated road management scheme has been partially tested and evaluated. Road operators have started to have at disposal a MDSS in which they have the possibility to check probabilistic bulletins as well as the data collected by six road weather stations installed in the test area (i.e. the one of Cadino plus other five additional installations). The complete demonstration of such automated procedures is going to take place in the last winter season covered by the project, i.e. the winter season 20152016, which will finally quantify the local benefits associated to this RWIS deployment. The long-term perspective is on one side to put the basis for an exploitation of such a system on the whole Autonomous Province of Trento, with the scaling up of such technologies and procedures among all road operators' teams. On the other side, such an initiative could pave the way for the deployment of advanced cooperative and automated scenarios, which could be studied in more detail in future project initiatives. This enhancement could be rather simple by looking at the overall CLEAN-ROADS architecture and by highlighting the possible cooperative and automated functionalities that could be added at a later stage.

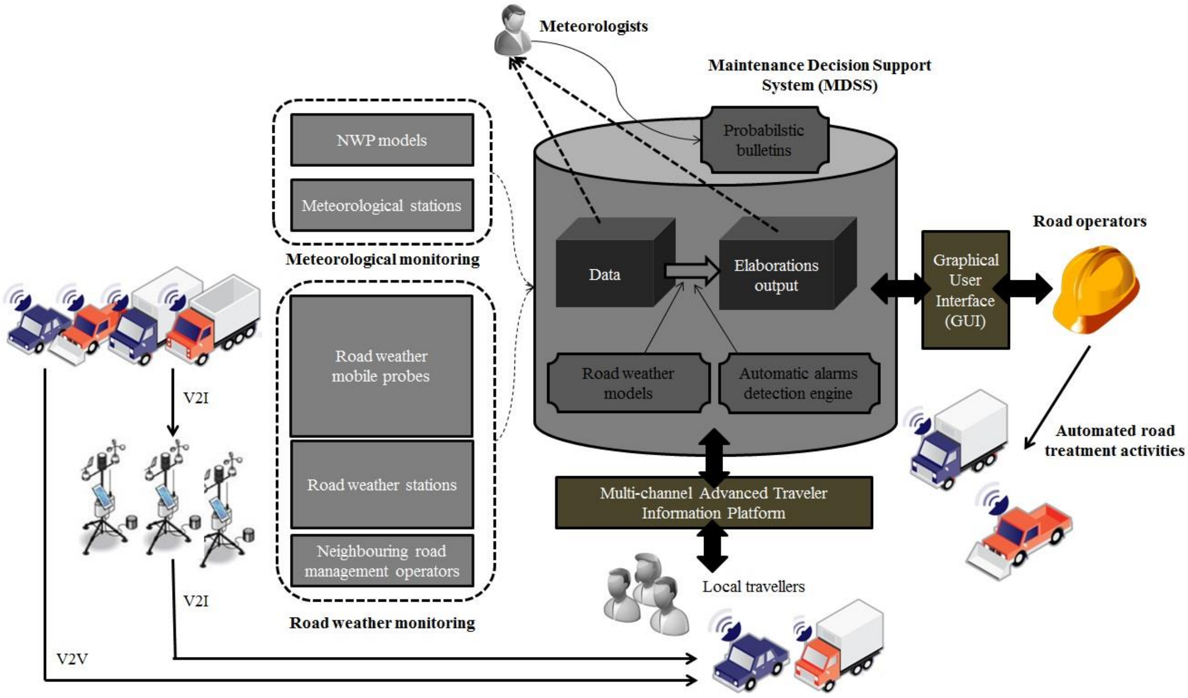


Figure 6: Current (in grey) and future (coloured) CLEAN-ROADS architecture.

The role of connected vehicles and the ubiquitous connection to road travelers will be increasingly important, in particular to address certain road weather events that are typically unpredictable and not properly addressable by traditional road maintenance activities, e.g. freezing rain. In such conditions, vehicles can be able to determine autonomously the presence of such risks and share this information to neighboring vehicles through V2V and to the road maintenance operators through V2I or vehicle-to-cloud communications. More generally, the extended Floating Car Data (XFCD) provided by different types of vehicles (e.g. road maintenance vehicles, other fleet vehicles, general public vehicles, etc.) can represent a very valuable source of less accurate but spatially distributed data, that could significantly improve for example the outputs of the XRWIS models. Such a contribution is already under evaluation in the project thanks to a demonstrative vehicle which has been properly equipped with additional road temperature sensors (Figure 7). Deployment costs of thermal mapping operations are today definitely cheaper, and the temporal frequency of such sessions can be therefore much higher than in the past. Furthermore, the possibility to take advantage of road weather data collected by third parties connected vehicles is completely changing the traditional role and contributions of the "mobile RWIS stations".

Figure 7: CLEAN-ROADS mobile RWIS station concept.

A direct consequence of these improved monitoring capabilities can be in the further automation of the proposed winter road management procedures. Road treatment plans could be adapted and enriched accordingly, in particular in terms of type and amount of deicing resources to be spread on specific route stretches. The elaboration of such plans could smoothly become an automatic task of the MDSS, with road operators just coordinating and organizing road treatment operations. Maintenance vehicles could moreover fine-tune such instructions on top of the real time road conditions data collected by its own on-board sensors and, if properly enabled by autonomous functions, could furthermore lead to a complete automation in such a winter road management architecture.

Open discussion points

The potential beyond the technological evolution of the CLEAN-ROADS implementation is clear. A similar development could really represent the right entry point for the large-scale deployment of cooperative technologies and automated road management schemes. The preliminary estimation of the cost savings has in fact demonstrated the potentially great economical sustainability of such technological solution to address such road management challenges. What is still unclear, at least for the local scenario of interest, is to quantitatively understand the cost / benefit improvement (including environmental issues) that can be obtained first by the fully deployed CLEAN-ROADS system, and second by the future cooperative and automated functionalities. The risk is that much of the savings can be obtained through the "first-stage" deployment, which could considerably cut the number of unnecessary road treatment actions; the "second-stage" deployment could instead lead to a further optimization in the resources usage, with a less remarkable optimization margin and as a consequence a more questionable convenience. Other issues are moreover to be taken into account, in particular liability. At present, road operators are fully responsible for their activities, but what if a road treatment plan is automatically generated by a MDSS and followed as it is? In conclusion, while technically an advanced RWIS implementation seems to be an interesting starting gate for the rapid deployment of cooperative and automated scenarios and applications in alpine environments, the impression is that more assessment studies are needed in order to properly explore their effective local potential and overcome other non-technical entry barriers, with the perspective to slow down a process which on the contrary could be even very fast. In this scenario, specific environmental concern like for example the ones related to the excessive usage of deicing chemicals could moreover play a central role for determine priorities in the future local road transport investments.

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