ID: 0019

The CLEAN-ROADS project: a combined environmental-cost-user gain from the application of a MDSS to winter road maintenance operations

Ilaria Pretto[1], Claudia Di Napoli[1], Elisa Malloci[1], Roberto Cavaliere[2], Roberto Apolloni[3], Guido Benedetti[1], Andrea Piazza[1]

[1] Autonomous Province of Trento, Via Gazzoletti 33, Via Vannetti 41, Via Mantova 16, 38121 Trento – Italy
[2] IDM Südtirol Alto Adige, Via Siemens 19, 39100 Bolzano – Italy
[3] Famas System S.p.A, Via degli Artigiani Sud 19, 39040 Egna (Bolzano) – Italy

Corresponding author's E-mail: ilaria.pretto@provincia.tn.it

ABSTRACT

This paper presents the final results from the CLEAN-ROADS experience. The CLEAN-ROADS project, an initiative co-funded by the European LIFE+ program, aims to examine the environmental benefits of applying an advanced Maintenance Decision Support System (MDSS) to the gritting operations currently adopted in the Autonomous Province of Trento (Italy) in preventing ice formation on roads.

Over three consecutive winter seasons road weather and surface condition data have been collected through a mobile probe vehicle and a state-of-the-art road weather information system (RWIS) of fixed stations. From this information base, a novel MDSS tool has been developed to report past and present roadway status, assess current weather conditions, provide nowcast and short-term forecasts of icy conditions, and automatically deliver alarms in case a risk of ice on the road is detected.

The novel MDSS has been applied to assist a road maintenance unit in de-icing operations operated in the Province along a test route. Its benefits to the environment have been empirically evaluated. By integrating the MDSS with an environmental monitoring system, the impact of de-icing salt (sodium chloride) on aquatic systems and air quality has been quantified, and the environmental gain due to a MDSS estimated for the first time.

The impact of a MDSS to the management of anti-ice treatments has also been analysed. The implemented MDSS recommends the necessity and timing of gritting the road with salt. A comparison between MDSS recommendations and the treatments actually carried out has permitted to (i) identify possible weaknesses in the current winter maintenance management system and (ii) improve the system itself in terms of efficiency and costs. In this paper the economic gain due to the novel MDSS is presented and quantified in a qualitative way, with detailed cost/benefit analysis expected to be finalized in the final project's months.

Finally, implemented strategies to increase the level of responsibility in road users are described. Benefits achieved from conducting awareness-raising actions about road ice and disseminating road weather information to local travellers through a MDSS are assessed and discussed.

Keywords: environmental impact, economic gain, integrated road/weather monitoring and forecast, MDSS, traveller information system.

1 INTRODUCTION

In winter time, when ice is likely to form on roads, road safety becomes a high-priority aspect both for road operators and travellers. The CLEAN-ROADS project, an initiative co-funded by the European LIFE+ program, aims to examine the environmental benefits of applying an advanced Maintenance Decision Support System (MDSS) to the gritting operations currently adopted in the Autonomous Province of Trento (Italy) in preventing ice formation on roads [1].

2 THE NOVEL CLEAN-ROADS MDSS

Over three consecutive winter seasons (2013-2014, 2014-2015, 2015-2016) road weather and surface condition data have been collected through a mobile probe vehicle and a state-of-the-art road weather information system (RWIS) of fixed stations. From this information base, a novel MDSS tool has been developed to report past and present roadway status, assess current weather conditions, provide nowcast and short-term forecasts of icy conditions, and automatically deliver alarms in case a risk of ice on the road is detected (Figure 1).

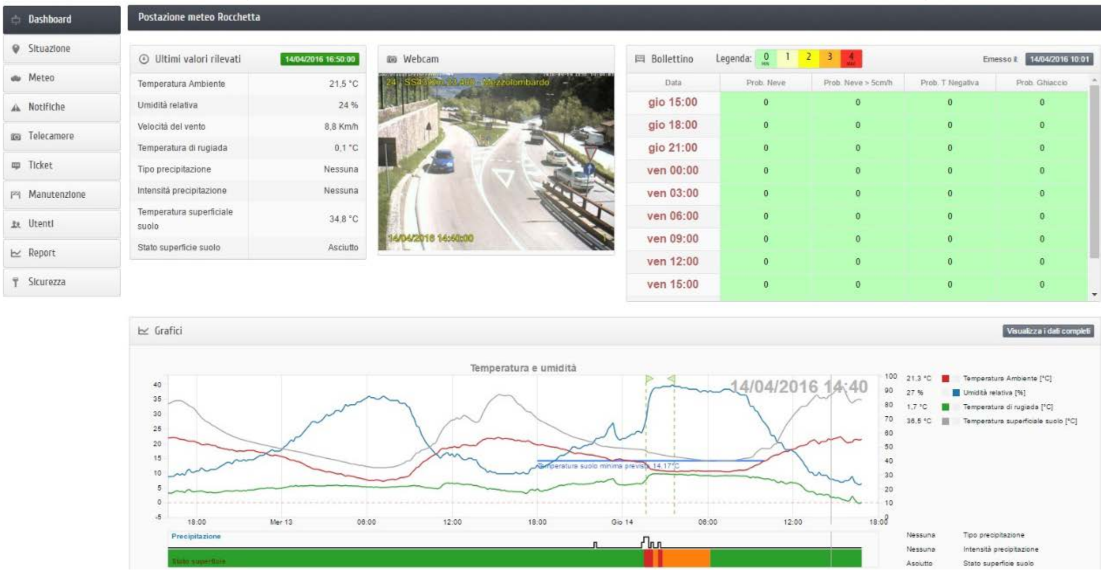

Figure 1: A part of the GUI of the MDSS dedicated to road-man workers.

This novel system is supported by a four-level hierarchical scheme [2]. Each level has been defined to represent a step towards a timely and effective preparation of preventive anti-icing activities. The scheme is as follows.

Level 0: RWIS data

A road monitoring network of fixed RWIS stations delivers real-time data for weather parameters, such as air temperature, dew point temperature, wind speed, solar radiation, and road weather parameters, such as road surface temperature. Weather radar data are also included to determine the location, speed and direction of precipitation (rain and snow).

Level 1: Probabilistic bulletins

On a daily basis the meteorologist in duty at Meteotrentino Weather Service interprets observational data from RWIS stations and forecast data from numerical weather prediction models (e.g., European Centre for Medium-Range Weather Forecasts, ECWMF), and translates them into a *probabilistic bulletin*, i.e. a brief report where a numerical value – a probability – is given for the occurrence of a meteorological event being forecast on the short time range (36 hours). Four critical events are considered, namely snow, heavy snow with accumulation rate greater than 5 centimetres per hours, negative air temperatures and road ice formation. Probabilities are issued according to a four-level scale: “0” for an extremely unlikely event, “1” for an unlikely event, “2” for a possible event (less likely than not), “3” for a probable event (more likely than not) and “4” for a very likely event. The scale is defined on the minimum risk criteria, i.e. to reduce the number of missed treatments.

Level 2: Road weather models

Road and atmospheric observations from RWIS are used as initial conditions for pavement heat balance models, specifically METRo (Model of the Environment and Temperature of Roads) and Reuter’s model. In METRo observations are also coupled to meteorological forecasts from ECMWF numerical prediction model. The overnight minimum value of road surface temperature (RST) is estimated automatically in the nowcast time range (6-9 hours) by combining the predicted value from METRo and the predicted value from Reuter’s model into one single forecast, as this increases forecast accuracy [3].

Level 3: Real-time warning system

Alarms associated to conditions of low road friction are defined according to weather and road weather data measured at the RWIS stations. Potentially slippery conditions include snow, precipitation on frozen road and ice/frost on untreated roads.

Levels 0, 1 and 2 are provided through a graphical user interface designed to display measured and predicted data plots and maps on fixed and portable devices. Road operators consult and interpret the interface every day before deciding on a possible preventive action. Level 3 is delivered via texts and calls, and alerts road operators to take immediate action against ice formation.

3 THE ENVIRONMENTAL GAIN

The novel CLEAN-ROADS MDSS has been fully integrated with an environmental monitoring system in order to quantify the impact of de-icing salt (sodium chloride) on aquatic systems and air [4]. The novelty of this application is to estimate the environmental gain obtained by applying a MDSS to gritting activities.

The Ambient Air Quality and Cleaner Air for Europe Directive (2008/50/EC) states that contributions to exceedances of particulate matter PM_{10} limit values that are attributable to road winter salting may be subtracted when assessing compliance with air quality limit values, once provided that reasonable measures have been taken to lower concentrations.

The impact evaluation of road salting practices on air quality was carried out by measuring the chlorine and sodium concentration in the PM. Winter 2013-14 was mild and characterized by a reduced number of road treatments and frequent rainfalls. These conditions made impossible to identify effects of salt spreading on NaCl concentration in air as salt was washed out from the road and only small amounts were resuspended in air. On the contrary, winters 2014-15 and 2015-16 showed a clear correlation between spreading and NaCl concentration, and between Na^+ and Cl^- concentrations (Figure 2). The presence of NaCl in air depends on the resuspension of salt from the road.

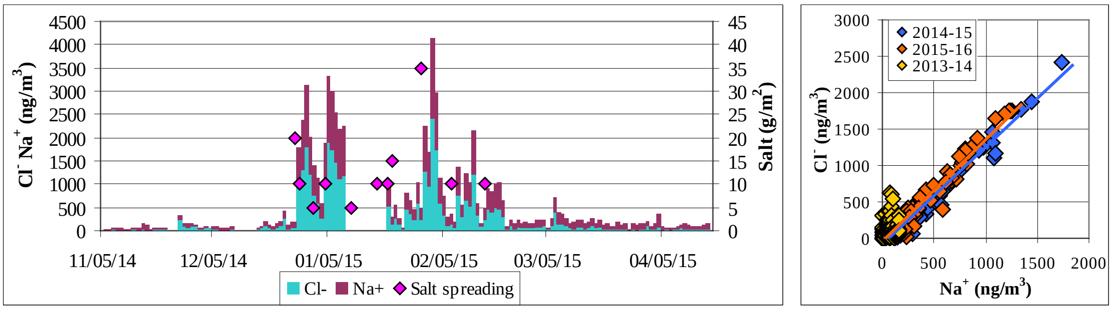

Figure 2: Correlation between salt spreading and NaCl concentration in PM10 (left panel) and concentration of Cl- and Na+ in PM10 samples (right panel).

The impact of road salting practices on water quality was measured considering several parameters. Figure 3 shows a comparison between rainfall or snowfall intensity over time (hyetograph) and runoff flow rate (hydrograph, calculated from the water level through a triangular weir). The concentration of pollutants over time (pollutograph) obtained from a discrete sampling during the runoff event, and "Event Mean Concentration" (EMC, expressed in mg/L) of the main pollutants in the runoff water, which is a synthetic parameter calculated from the pollutograph with a flow-weighted estimation, were also considered to evaluate the salting impact (Figure 3).

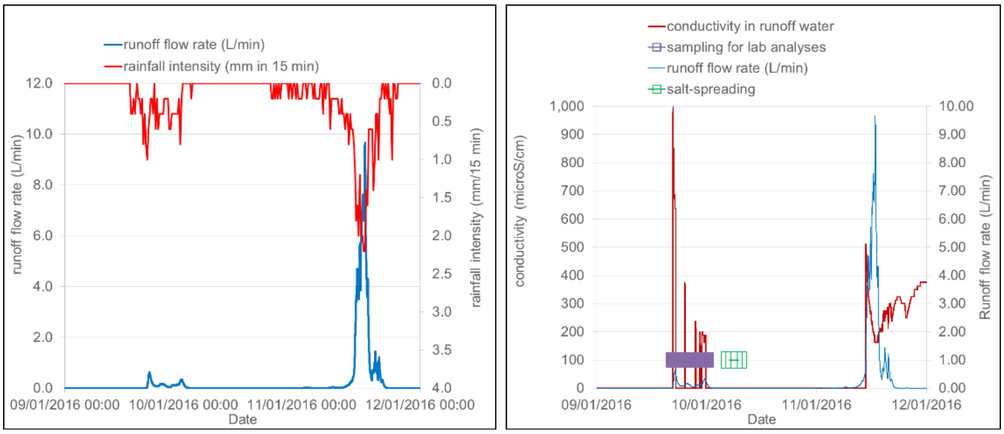

Figure 3: Data of rainfall intensity and the corresponding runoff flow rate (left panel) and comparison between conductivity data and salt spreading operations (right panel).

Results highlight that the NaCl presence in air and in runoff water strongly depends on the weather conditions present after gritting. When performed in dry conditions (e.g. no rainfalls) salting operations immediately increases NaCl concentrations in air. After a light rain low concentrations of NaCl are detectable in runoff water, while high concentrations are detected in air (some days after spreading). On the contrary, low presence of NaCl in runoff water is detectable if the road treatment is not followed by any rainfall. Finally, if the salt spreading is immediately followed by a heavy rainfall, almost all the NaCl is detectable in the runoff water.

This environmental analysis helped to identify some "unnecessary road treatments", which, in this case, correspond to salt being spread before a heavy rainfall. In this case almost all the NaCl is washed out by the runoff water and cannot perform the function for which it has been originally spread.

4 THE ECONOMIC GAIN

With the CLEAN-ROADS project weaknesses and strengths have been identified in the winter road maintenance management system adopted before the introduction of the novel MDSS. One of the main strengths is the commitment of the road operators' team involved in the project, who has always operated by making the best choices for road safety. This however might also represent a weakness. Some of the treatments performed for guaranteeing road safety can be indeed identified as "unnecessary". Unnecessary road treatments can be divided in three main categories:

1. **Road treatments when road conditions are far from ice-formation conditions**: before the CLEAN-ROADS MDSS introduction road operators have been found to overestimate ice formation risk in some situations. As such, they used to grit roads even when not necessary. By providing the CLEAN-ROADS MDSS tool with the four-level alarm system, road operators are informed in advance about the likelihood of ice formation and can therefore plan road treatments according to a real risk of ice formation.
2. **Road treatments followed by heavy rainfalls**: before the CLEAN-ROADS MDSS introduction road operators used to grit when they felt uncertain about the likelihood of a precipitation as rain or snow. This class of treatment has been made avoidable by providing an affordable, detailed and site-specific probabilistic weather forecast through the MDSS. At the same time, the constant automatic monitoring of real-time data via RWIS stations helps to promptly identify situations where meteorological conditions may change quickly and may therefore need road treatments that originally were not planned.
3. **Heavy rainfalls followed by a road treatment**: before the CLEAN-ROADS MDSS introduction road operators used to make treatments after a heavy rainfall when air temperature is above 0°C so that a minimum quantity of salt could always be present on the pavement. The CLEAN-ROADS system demonstrates that a high percentage of these treatments is avoidable when road conditions are forecasted to be far from ice formation risk. In order to cut the number of unnecessary treatments, the CLEAN-ROADS project revealed the necessity to introduce the experimental use of pre-wetted salt instead of solid salt.

The CLEAN-ROADS project team intends to numerically quantify the economic gain derived by reducing the number of unnecessary treatments through the application of the novel MDSS through a cost/benefit analysis. Results will be available at the end of the project in September 2016.

5 THE USER GAIN

An efficient balance between road safety and impact from winter road maintenance activities can be fully achieved when travellers become actively engaged in the system. The involvement of road users has been one of the most challenging aspects of the project. In general travellers demand ideal road conditions under all meteorological events (heavy snowfalls included). They thus expect the winter road maintenance service to guarantee the best road environment for drivability anytime and anywhere. However most of road safety issues occurring in winter time are related to inappropriate driving behaviour. One of the goals of the project has therefore been to put the basis for a change in the actual local travellers' perspectives.

For this purpose a prototype informative service has been developed in the form of a HTML5 web application. The application is available at the website http://map.clean-roads.eu/ and presents a Graphical User Interface (GUI) optimized for visualization from portable devices such as smartphones and tables (Figure 4). The application is linked to the CLEAN-ROADS MDSS and displays a sub-set of the real-time road weather data collected by the static road weather stations, namely road/air temperature, wind speed and humidity. In case of rainy/snowy precipitations, the event is displayed on the map through a specific additional icon, which also indicates the intensity of the precipitation. Furthermore, the application informs travellers about where the road temperature is getting "cold" so that they can get familiar with a new concept of "road safety level". In "cold" conditions (at present defined when road

Figure 4: The CLEAN-ROADS Graphical User Interface (GUI)

temperatures are below 2°C) drivers become aware that icy hazards might locally appear , independently from the treatments carried out by the road maintenance service.
This system has been developed in a way that it could easily exploitable and expandable in the future, specifically by taking advantage of cooperative systems and open data logics. On one side, this information might be transmitted on-board through V2X channels, and thus be much more effective in terms of adaptation of the driving behaviour, in particular in the future perspective of autonomous driving. On the other side, the potential of connecting the CLEAN-ROADS MDSS to third-party information services according to the open data approach opens the door for a more efficient connection with all specific users' targets during all their phases of the trips.
During the whole project local travellers have been actively engaged in different involvement activities, the most relevant of which have been in the form of online questionnaires. In the ex-post survey, organized at the end of the winter 2015-2016 (when the final web application has been made publicly available), 83% out of 265 participants have considered this new type of service at least as "rather useful". This result is quite promising in a perspective of a future exploitation of similar services.

6 CONCLUSIONS

This paper presents the preliminary outputs of the CLEAN-ROADS project and the main achievements achieved in the winter road maintenance sector. The acquisition of road weather data through a state-of-the-art RWIS enables a novel MDSS to perform a four-level alarm system which helps road operators in performing timely and effective road treatments and avoiding unnecessary ones. In this study we demonstrate that meteorological conditions are key factors in influencing the environmental impact of de-icing products on water and air component. By optimizing the number of anti-icing treatments, the concentration of NaCl in air and water is reduced. Furthermore, the CLEAN-ROADS project has started to positively influence the local travellers' self-commitment towards more conscious driving styles. In order to actively involve travellers and give them the chance to plan their trips according to real-time road weather conditions, a novel traveller information service, the first in its type in the north of Italy, has been developed and launched. From an economical point of view, we expect a significant reduction of de-icing treatments and therefore a viable business case for economically sustaining and further developing the prototype system developed. In particular, the vision is to extend the CLEAN-ROADS system to other roads within the Trentino Alto-Adige region and other nearby mountainous areas, and where possible to further improve and refine the technological solutions deployed. Numerical results and future exploitation plans will be provided by the end of the CLEAN-ROADS project in September 2016 and make publicly available through the project web site www.clean-roads.eu.

ACKNOWLEDGEMENTS
Project partners would like to thank the European Commission and the LIFE+ program for the financial support received, and the SIRWEC 2016 organization committee for giving the possibility to present CLEAN-ROADS to the international road weather community.

BIBLIOGRAPHY

[1] Pretto, I. et al., "Addressing the environmental impact of salt use on the roads: the CLEAN-ROADS project", SIRWEC 2014 conference proceedings, ID:0019 (2014).

[2] Cavaliere, R. et al., "Automated winter road management procedures: an entry gate for advanced ITS deployment?", 22nd ITS World Congress, ITS-2235 (2015)

[3] Di Napoli, C. et al., "A combined road weather forecast system to prevent road ice formation in the Adige Valley", Geophysical Research Abstracts 18, EGU2016-563 (2016)

[4] Pretto, I. et al., "CLEAN-ROADS project: air quality considerations after the application of a novel MDDS on winter road maintenance activities, Geophysical Research Abstracts 18, EGU2016-14101 (2016)