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Addressing the environmental impact of salt use on the roads: the CLEAN-ROADS project

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ABSTRACT

The paper presents the RWIS experience which has recently started in the Province of Trento (an alpine region in the north of Italy) within the EU LIFE+ project "CLEAN-ROADS". The project aims to locally quantify the impact on aquatic systems and air quality which is caused by a wide use of de-/anti icing chemicals during the winter road maintenance operations, and to empirically assess the environmental gain which is produced by the introduction of an advanced RWIS characterized by fixed stations and mobile probes. A demonstrative Maintenance Decision Support System (MDSS) will be developed with the purpose of improving the procedures of interventions of the regional road management service, i.e. with the target to guarantee at least the today's level of service but with a significant optimization in the efficiency of how available resources are currently used. The demonstrative system will be tested and validated on a test area located in a valley bottom, where the highest optimization margins are to be expected. The project does not only have a technological dimension, but also a social one: on one side, road operators have been strongly involved in the requirements' definition process and will actively contribute during the whole implementation chain; on the other side dedicated awareness-raising actions are planned in order to increase the level of responsibility of local travellers when planning and/or carrying out a journey during the winter season. In order to foster this behavioural change process, local road users will have also the chance to take advantage of improved traveller information services.

Keywords: environmental impact, targeted weather forecasts, integrated road monitoring system, MDSS, social dimension.

1 INTRODUCTION

The CLEAN-ROADS project is an initiative co-funded by the LIFE+ program of the European Commission started in September 2012, which aims to address the environmental problem caused by a wide use of de-/anti icing chemicals during the winter road maintenance operations in the Province of Trento. Today, local winter road treatments, despite managed through a well-organized structure, are carried out mainly on the base of subjective criteria, and do not directly rely on quantitative data coming from the field. The natural consequence for this is a probable overestimation of the amount of required salt and thus a waste of resources, in particular in correspondence of conditions in which the boundary between the decisions of making a treatment or not is not clearly evident. The objective of CLEAN-ROADS is not only to deepen and quantify at a local level the environmental impact produced by salt in the ecosystem near the road infrastructure, but also to demonstrate that a non-negligible gain in this domain is possible if road operators could have at disposal a Maintenance Decision Support System (MDSS) for making more efficient decisions on how to plan the winter road treatments. Through the comprehensive glance about current and forecasted road conditions offered by the MDSS, the Road Management Service of the Autonomous Province of Trento, in cooperation with its Weather Service and Environmental Agency, will be in the condition to advance its procedures of interventions, and maximize the utility and the impact of each single treatment action.

1.1 The road weather situation in the Province of Trento

The Autonomous Province of Trento (PAT) is one of the largest territories in Italy, with an extent of about 6,207 [km^2]. The region is mainly a mountainous area, more than the 49% of the whole territory is in fact covered by woods (Figure 1). Temperatures can easily reach in the winter time values of -15, -20 [°C], particularly in the valleys and reliefs in the north. Climate patterns in the region are very heterogeneous and can vary quite differently from winter season to winter season. Regarding snow precipitations, the levels increase with the altitude. 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]. Because of its local autonomy, the PAT is in charge not only of the maintenance and the modernization of the local roads, but also of the national ones. The whole road infrastructure managed by the PAT extends for about 2,445 [km], and about a 10% of the whole network (about 245 [km]) is characterized by an Average Daily Traffic (ADT) of more than 10,000 vehicles.

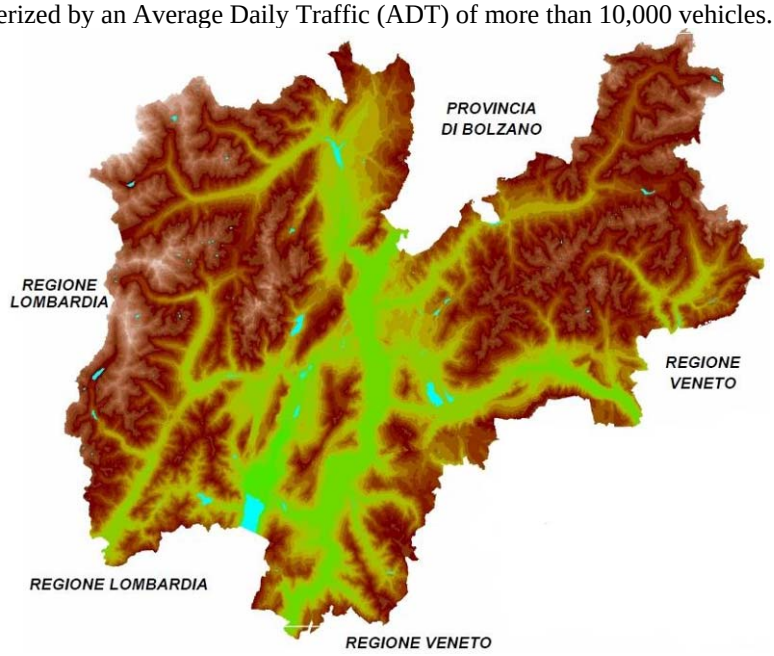

Figure 1: The orography of the Autonomous Province of Trento.

1.2 The local winter road maintenance organization

During intense snowy winter seasons, up to 20.000 [tons] of salt can be overall used all over the PAT; this quantity can be significantly decreased (even more than halved) when the number of snowfalls is significantly reduced. Sodium chloride (NaCl) is the most used de-icing chemical to prevent the formation of ice or to prevent the accumulation of snow and its transformation in ice during the winter precipitations; other chlorides are in general avoided. The maintenance of the road network is under the responsibility of the Road Management Service, and is organized in eight different sectors. Each sector has an own central management headquarter and is coordinated by a specific sector manager. The ordinary and extraordinary maintenance of the vehicles and the equipment used during the winter road maintenance activities is done at a central yard, which is shared among all sectors. During the winter season (usually from October to April) a special surveillance road service is activated. The service is organized in weekly shifts, where workers must constantly verify the climatic-atmospheric conditions during the night time and in the weekend. Moreover since winter season 2005-2006 a reference emergency coordination plan, shared among different public organizations, has been introduced for the definition of the specific procedures to be followed in case of intense snow events. The maintenance of the roads during the winter season is a very demanding tasks and requires a lot of financial and human resources; as a matter of example, it is worth noting that only the purchase of salt is on average equal to 1.5 million €, which is a quantity that is destined to increase in the near future because of the continuous increase in its price.

1.3 The environmental impact

The impact of road salt on the local environment has been deeply assessed in the scientific literature in the past years, and various works such as [1] have given a quantitative evidence of the negative consequences that can be observed on different matrixes, in particular aquatic systems, air quality, vegetation, wildlife and human health, without forgetting the observable damages on vehicles and the road infrastructure itself. At present, there is not a clear evidence of the relevancy of this problem at local level; in particular, it is estimated that a non-negligible

number of winter PM_{10} measurements presenting values clearly above the admitted law thresholds (e.g. daily average concentration of maximum 50 [µg/m^3]) is related to salt dispersion phenomena in the atmosphere caused by the wind action or the dust re-suspension caused by vehicular transits.

2 THE SCOPE OF THE CLEAN-ROADS PROJECT

The CLEAN-ROADS project aims to specifically address the current limitations of the winter road maintenance operations and the lacking knowledge about their impact on the environment. More in particular, a multiple innovation helix is going to be fostered through the project activities, which are organized in order to tackle the addressed problem through a multi-disciplinary approach:

- **technological innovation**, through the introduction and validation of an integrated Road Weather Information System (RWIS) and a MDSS capable to automatically provide user-friendly recommendations, information and alerts to road operators about the current and forecasted road weather situation;
- **organizational innovation**, aimed at improving the current winter road management organizational structure; in particular the intention is to refine and to better codify the existing procedures on the base of the specific decisions that can be determined on top of the outputs coming from the MDSS, and that aim to guarantee at least the today's winter road safety levels through a more efficient use of road maintenance resources and a clearly demonstrated environmental improvement;
- **social innovation**, through an intense cooperation with the target audience, to be intended not only in terms of road operators belonging at various levels to the road management staff, but also of local road travellers, who have already shown very high requirements and expectations in this field but are on the contrary the first responsible of many situations of inefficiency that may be observable on the local roads during the winter season.

So, apart from the technological peculiarities investigated in the technical dimension of the project, which are described more specifically in the following chapter, an interesting contribution to the international RWIS community is related to the "social dimension". More in particular:

- **road operators** will have a fundamental role in the entire process of MDSS development, from concept definition to its final empirical validation. This element will minimize the acceptance risks that the introduction of a technological instrument such as a MDSS may cause. Background knowledge of road maintenance staff is also fundamental in order to experience concrete benefits, and for this reason several training sessions are going to be organized in the scope of the project;
- **local travellers**, who will be an active part of the CLEAN-ROADS system, since they will directly benefit from real-time road weather information distributed through the available traveller information channels (Variable Message Signs, online applications, etc.). Dedicated awareness-raising actions destined to specific target groups (e.g. tourists) are moreover going to be organized with the aim to increase the level of responsibility of local travellers in the organization and planning of trips during the winter seasons and in the proper adaptation of their driving style as a function of the specific road conditions. In this way, the goal is to reach a new balance between road users' expectations and dimensioning of road maintenance activities, which are today negatively influenced by responsibility issues and the very demanding needs of road users, in particular less experienced ones;
- finally, being the topics and the environmental concern covered by the CLEAN-ROADS project of global relevancy, the project aims also to create active exchange activities with **inter-regional, national and European stakeholders**, organizations and networks, with the intent to learn and study alternative solutions that are applied in similar and/or different environments. In this way, it will be possible not only to share and amplify the resonance of the topics developed in the project, but also to put the premises for creating the opportunities for the diffusion of similar practices in other realities, in particular in Italy where winter road maintenance is a hot topic but very little addressed by initiatives such as the CLEAN-ROADS one.

3 THE CLEAN-ROADS SYSTEM

A state-of-art RWIS fully integrated in a MDSS and with an ad-hoc environmental monitoring system is going to be tested and validated within the CLEAN-ROADS project. From a methodological point of view, the project is going to follow the well-known V-model approach (Figure 2), which is a common structure for engineering processes, especially in the field of ITS pilot project [2].

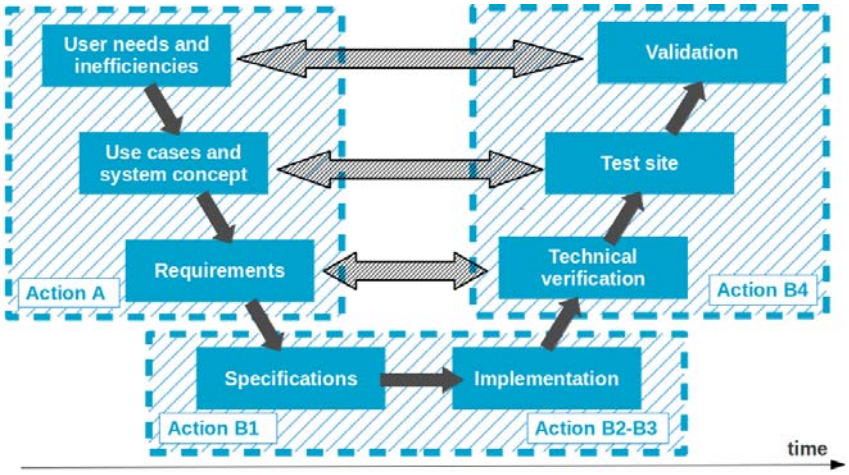

Figure 2: The V-model approach adopted within CLEAN-ROADS.

The basic idea of this approach is to verify the functionalities of the proposed system within a Field Operational Test (FOT) through a three-steps evaluation process:

- **technical verification**, i.e. by properly evaluating if the system prototype is able to verify the functional requirements;
- **test site situations check**, i.e. by verifying the possibility to effectively create in practice all set of reference "use cases";
- **final system validation**, i.e. by analysing if the system is in the condition to efficiently match the needs of the final users identified at the project start.

3.1 The initial assessment of reference user needs and inefficiencies

Preparatory actions "A" have in particular tried to investigate the addressed problem through a mixed analysis of user needs and inefficiencies estimation, use cases and requirements identification. During this process, a deep evaluation of the actual technological progress and limitations in the RWIS domain, as well as the identification of the most interesting best-practices, has been put in direct relationship with the perspective of both road operators and local travellers. In particular, road users' feedback has been collected through an online survey which has managed to collect more than 1.000 inputs in a couple of months. The answers to the proposed questions have been analysed following the evaluation methodology suggested by Takahashi et al. in [3], and have mainly demonstrated the different perspectives of drivers who have revealed to have a more or less intimate relationship with their private car. The expectation towards the local road maintenance service has demonstrated to be, as expected, much higher in users in which this relationship is weaker, and the general opinion is that most of the observed inefficiencies is related to the inexperience and the reduced preparation of road travellers. A comprehensive overview of the Customer Satisfaction Analysis is given in Figure 3; for more details about the results of this survey, we recommend the reader to directly refer to the deliverables published on the project's web site, in particular [4]-[5].

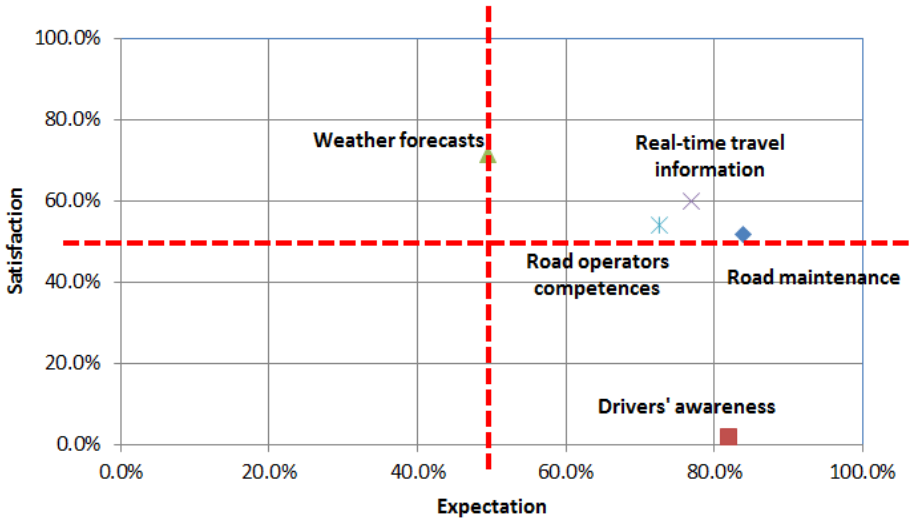

Figure 3: The results of the local travellers' CSA carried out in the preliminary evaluation process.

3.2 The system concept and the elements of technological innovation

One of the main output of this initial requirements' evaluation process has been the consolidation of a reference high-level system architecture, which has been defined also in order to the pave the way for the future cooperative ITS that are going to be largely deployed in the coming years, and that are currently under investigation in this domain in project initiatives like WiSafeCar [6] and CoMoSeF [7] or within the Road Weather Connected Vehicle Applications coordinated by the US Department of Transportation – Research and Innovative Technology Administration. The CLEAN-ROADS system concept, presented in Figure 4, is based on the idea to introduce a full chain among the multiple sources that are in the conditions to gather various road weather measurements (and not only, i.e. environmental data), the MDSS in which most of the validation, elaboration and prediction analysis are computed, and the Advanced Traveler Information System (ATIS) which is capable to distribute relevant road weather information through multiple information channels. As far as the environmental impact is concerned, the focus of the project is mainly on two matrix: (i) air quality, which is going to be assessed through roadside air quality measurements, and (ii) aquatic systems, which is going to be investigated through specific evaluation of the salinity concentration of run-off waters. By putting these measurements in direct relationship with the salting treatments, it will be possible to quantitatively assess the consequences of those actions on the road environment.

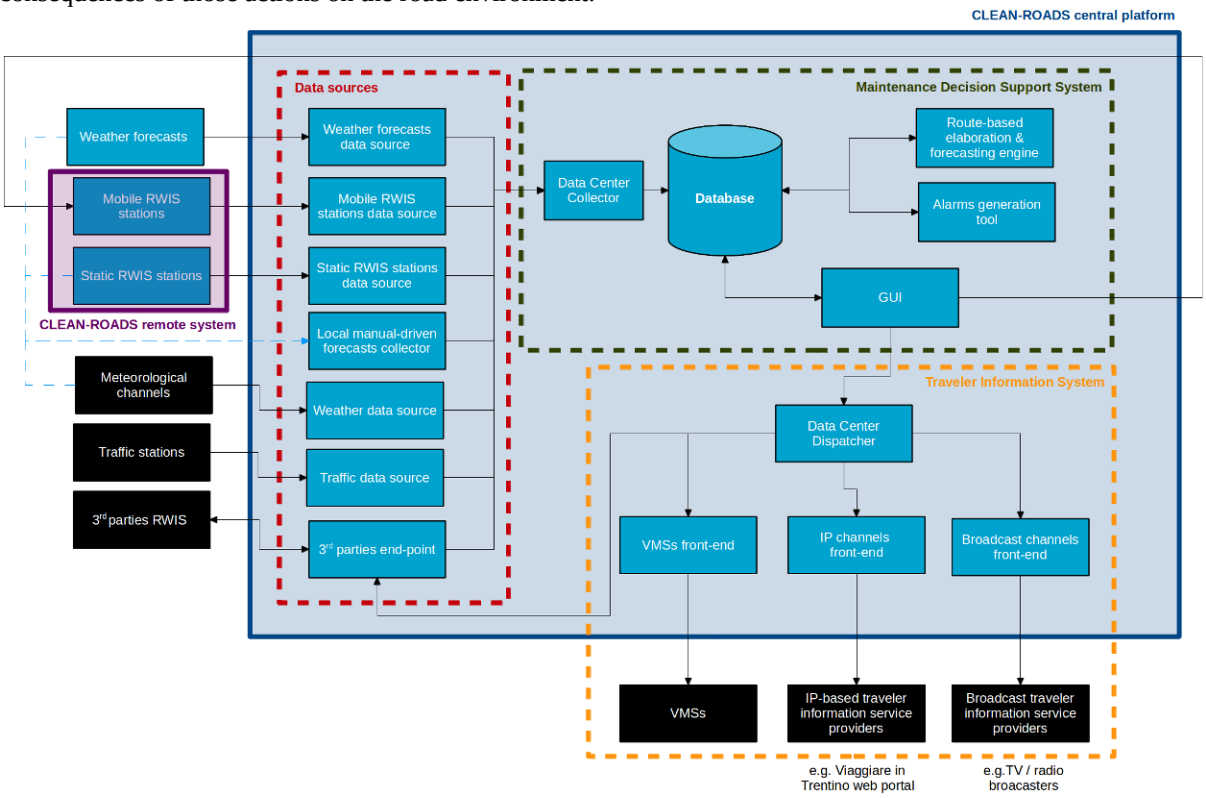

Figure 4: The high-level architecture of the CLEAN-ROADS system.

The most interesting components and elements of the proposed architecture that are worth to be mentioned are the following:

- **efficient combination of data gathered by fixed stations and mobile probe vehicles**. Within the project, novel road detection solutions will be investigated, both in terms of fixed stations (e.g. non-invasive road conditions measurements, energy-efficient elements integration, combination of monitoring points with different detection capabilities) and mobile probes (e.g. parallel measurement of road surface temperature in correspondence of different points of the road section). At present, it is not perfectly clear in the road weather community how to best integrate all this plenty of information. What we suggest to do in CLEAN-ROADS is to use the fixed measurements to calibrate the road weather model that is going to produce the route-based elaborations and forecasts, and to integrate the mobile probe data in order to improve the spatial resolution of the model outputs by mainly identifying localized risky conditions. This approach would probably better take in consideration the fact that mobile measurements are typically less accurate than fixed ones, and that they are to be considered mostly in quantitative than qualitative terms;
- **route-based elaborations and forecasts**. In CLEAN-ROADS, we are going to consider state-of-art models such as METRo, FASST and others, and not neglecting the potential beyond statistical

approaches. These models are going to be fed by the outputs of reference weather forecast models such ECMWF (16 [km] resolution) or models with higher spatial resolution such as COSMO N2 RUC (2,8 [km]) or WRF (2 [km]). The spatial extension will be determined on the base of a mix of different approaches, in particular by integrating a database of geographical parameters as suggested by Chapman et at. [8]-[9] and by properly aggregating the measurements taken by fixed stations as suggested by Shao [10]. The potential of 3D modelling approaches which is intrinsic in hydrogeological models such as GEOtop will be moreover investigated;

- **tailored (non-probabilistic) weather predictions**. In [11], Chapman gave a perspective of the future potential of probabilistic road weather forecasting. Based on the local experience and indications received by end-users, the idea of CLEAN-ROADS is to combine the automatic outputs of the road weather model(s) with tailored weather predictions which are going to be specifically prepared by the Weather Service for the road maintenance staff based on a cost/loss analysis that maximizes the compromise between false and missed alarms;
- **full integration with other ITS systems**, in order to give a comprehensive assessment of what is happening on the road infrastructure under control and not only, information coming from other traffic control centers and/or similar MDSS could be included. The inclusion of traffic information could be valuable not only for improving the output of road weather models, but also to give the possibility for more integrated (and thus effective) intervention strategies;
- **full integration with an advanced ATIS**, by following the relevant work done in EU projects like In-Time and Co-Cities which have proposed a harmonized data model compliant with the main traffic information exchange standards and a Business-to-Business (B2B) approach for the delivery of advanced traffic information services to travellers [12]. By including this sub-system in the architecture it will be possible in a near future to explore the local potential of connected applications driven e.g. through vehicle-to-infrastructure (V2I) communication technologies.

4 THE FIELD OPERATIONAL TEST

CLEAN-ROADS is a demonstrative project, and the suitability of the proposed concepts will be specifically tested and validated on a limited pilot test site. The main purpose of this Field Operational Test (FOT) is to demonstrate the validity of our approach and to understand how the overall system could be exploited on a larger scale in the whole region, eventually in cooperation with other local authorities (e.g. municipalities). The selected route is the stretch of route SS12 maintained by the Province of Trento; SS12 is one of the most important regional roads located at the valley bottom; the test route connects the local villages Lavis to the Bolzano Province, nearby the Salorno village (Figure 5), with a total length of about 14 [km]. The selection of this area has been done carefully, in particular by taking in consideration its representativity character (e.g. relevancy of geographical features like topography and sky-view factor) and on top of the consideration that the most relevant optimization margins are to be found at these low altitudes, where the boundary between the decisions to carry out a treatment or not is much narrower.

Figure 5: The case study road of CLEAN-ROADS.

The project evolution is very strictly linked to the winter seasons. The field activities have started in winter season 2012/2013 (i.e. immediately after the project start); during this period, road operators activities were

started to be more specifically recorded and their details directly correlated with available meteorological, traffic and accident data in order to start quantify the effective inefficiencies to be targeted.
The ex-ante evaluation is going to be fully completed during the current winter season 2013/2014 thanks to the measurements taken by a complete fixed station capable to cover also the above mentioned environmental monitoring activities as well, which will be spatially extended through the first thermal mapping investigations. In order to address the environmental impact on air quality, the daily average PM_{10} concentrations measured by gravimetric standards are taken in consideration, with the aim to correlate them with road salting activities . The chemicals components in the particulate are therefore analysed in the laboratory for specific source apportionment evaluations. The impact on the aquatic system is finally quantified both measuring chloride concentrations in the superficial runoff and, where applicable, evaluating consequences for biotic component in the water ecosystem.

A complete description of the pilot actions that are going to be carried out during the winter seasons is given in Table 1; four other fixed stations, probably simpler than the first ones, are going to be installed in 2014.

Winter season	***Activity set***	***Monitoring phase***
2012/2013	• the winter road maintenance procedures are empirically evaluated; • a comparison with a first reference dataset is performed, consisting of: o traffic data measured in correspondence of the test site; o meteorological data and forecasts;	Ex-ante evaluation (part 1)
2013/2014	• a first complete data collection campaign is carried out, availing of: o the first complete roadside road weather station; o the mobile probe; • first test sessions of the CLEAN-ROADS components are performed, in particular different road weather models will be tested on top of the available field measurements;	Ex-ante evaluation (part 2)
2014/2015	• the whole CLEAN-ROADS system is tested, calibrated and technically validated; • the road operators start to consider the data and the information provided by the MDSS, but in a unstandardized way;	Progress evaluation
2015/2016	• the CLEAN-ROADS system is finally evaluated and demonstrated through the introduction of optimized and standardized winter maintenance procedures.	Ex-post evaluation

Table 1. The pilot activities scheduled for the project's winter seasons.

Figure 6: The first complete fixed monitoring site.

5 CONCLUSIONS

The paper has given an initial presentation of the objectives and the topics of interest covered by the CLEAN-ROADS project, a EU initiative co-funded by the LIFE+ program and carried out in partnership between the Autonomous Province of Trento, the local private company Famas System S.p.A and the innovation centre TIS innovation park S.c.p.A. The novelty of this project is not only to be associated to its location – similar initiatives are quite rare for the Italian context, but also to the multi-disciplinary approach which is considered in order to efficiently target the reference inefficiencies that can be observed on local roads during the winter seasons, in particular to investigate the local concerns related to the environmental impact of salting treatments. CLEAN-ROADS aims at (i) specifically understanding if and how technological solutions such as a MDSS can lead in a particular environment like the Autonomous Province of Trento to an optimal use the available resources (i.e. including staff and equipment) through an evolution of the already well-structured winter road management organization, and (ii) activating a process towards local travellers for decreasing their actual expectations, which have demonstrated to be very high in particular among less confident drivers (e.g. tourists). The involvement of the end-users in the system loop can be crucial in order to reach a more effective balance point between users' expectation and levels of service, which is going to further evolve once road weather connected applications will be deployed on large scale.

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