LIFE+11 ENV/IT/002

CLEAN-ROADS

Action A1:
Experimental data collection campaign during a winter season

D.A1.2

Experimental data collection campaign – detection choices and technical features

Project Coordinating Beneficiary	Provincia di Trento (PAT)
Project Associated Beneficiary n.1	Famas System (FAM)
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[1] **PU** = Public.
CO = Confidential (accessible only by project partners and European Commission).
RE = Restricted Access, i.e. confidential but with a special access to a specific target of stakeholders defined by the project consortium and approved by the European Commission.

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1. Introduction

This report aims to present the preparation activities carried out in the scope of Action A1 concerning the activation of the five road weather monitoring stations for the collection of a set of baseline data set during the first winter season of the project.

The original project plan was to immediately install all roadside stations during this preparatory phase, and to scale them up during the project execution as a function of the implementation of the whole advanced RWIS system.

Technical and organizational constraints have immediately emerged, namely:

- the limited **time availability**, since the period of baseline data collection corresponds to the winter season, and the delayed start of the project has given little time to organize extensive measurement sessions;
- the availability of **power supply** in the road network of interest, which is necessary for the proper functioning of the roadside monitoring stations.

Given these premises, project beneficiaries immediately realize that a less ambitious plan would have needed in order to match a minimum set of goals required by the baseline data collection need. According to the Technical Supervisory Board, a more efficient solution would have been to:

- concentrate all initial road monitoring actions at a **specific test site**;
- give more emphasis to the **collection of information concerning the winter maintenance activities of the road operators**.

As a consequence, the other four road weather stations would have been installed in the test area in a second phase. The main advantage of this decision would have been that their position could have been optimally defined as a function of the results of the data evaluation collected during the first winter campaign. The decision to follow this recovery plan was taken during one of the first technical meetings after the official project start, in September 2012.

Unfortunately, the bureaucratic delays inside the Province of Trento concerning the approval of the external expenditures required for covering both the infrastructure works which were necessary for the installation of the roadside road weather station and the purchase of dedicated equipment to be installed in correspondence of this monitoring site (i.e. the air quality monitoring station) did not allow to activate in time this automatic data collection process. In fact, the road weather station was installed between March and April 2013, and thus too late for acquiring relevant data for the project's purposes.

Therefore, it has not been possible to collect a first, complete set of data to be used for the initial assessment of the effective optimization margins in the winter road maintenance operations, since the data concerning the winter road maintenance operations cannot be directly and punctually correlated with the measured road weather conditions.

For this reason, a more impacting recovery plan was urgently defined and approved by all project beneficiaries in the first months of year 2012. The plan tends to reschedule the set of activities to be carried out during all winter seasons of the project, but with the purpose of not affecting the technical execution of design and implementation activities, thus minimizing the impact on the original project plan. The recovery plan is illustrated in Table 1.

Winter season	Revised activity set	Original activity set

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;
		• a first complete data collection campaign is carried out, availing of:
		  o the full set of roadside road weather stations;

2013/2014	• a first complete data collection campaign is carried out, availing of:
	  o the first roadside road weather station;
	  o the mobile RWIS station;
	• first test sessions of the CLEAN-ROADS components are performed;
		• a first complete demo of the CLEAN-ROADS is installed on site;
		• the road operators start to consider the data and the information provided by the system prototype, but in a unstandardized way;

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 advanced RWIS system, but in a unstandardized way;	• the final version of the CLEAN-ROADS system is tested, calibrated and technically validated; • the CLEAN-ROADS system is finally evaluated and demonstrated through the introduction of optimized and standardized winter maintenance procedures.
2015	• the CLEAN-ROADS system is finally evaluated and demonstrated through the introduction of optimized and standardized winter maintenance procedures.	• the CLEAN-ROADS system starts to enter fully in operation in the test site area, eventually evolved by means of the experience gathered in the winter season 2014/2015.

Table 1: The re-allocation of empirical project activities during the different winter seasons of the project.

It is important to point out that despite all this set of critical issues, the proposed plan, being more conservative, is probably more effective than the original one, since:

- the baseline data assessment is performed among two different and consecutive seasons, with the possibility to **improve the details of the targeted problems and inefficiencies**, and as a consequence to **maximize the effectiveness on how the CLEAN-ROADS system is designed and implemented**; moreover, seasonal effects related in particular to the total amount of precipitation fallen during the winter season can be more efficiently taken into account and compensated;

- **the definition of the position of the latter four roadside monitoring stations** will rely not only of roadside road weather data, as originally stated in the initial recovery plan, but also on the data collected by the thermal mapping operations which will be carried out by the **mobile RWIS station** prototype. This will allow the unexpected potential to determine this choice also from a quantitative point of view, since the position could be selected in a very precise way in order to maximize the ability of the system to model the actual and forecasted road weather conditions;

- the **road operators will start to use the CLEAN-ROADS system a winter season later than expected**, with the possibility to increase the level of acceptance and involvement of the personnel staff and at the same time to provide them a system prototype which is hopefully more stable and fully-developed; this aspect must be properly however compensated by a higher level of involvement of the road operators during the implementation phase, in order to address their expectation to get something concrete which can support their maintenance activities. For this reason, it is envisaged that they can start to actively test and evaluate the user interfaces of the system already from the beginning of Action B2 in a more intense way than originally foreseen.

- a **full winter season is dedicated for the final evaluation of the optimized and standardized winter maintenance procedures**. In the original plan, this test bed phase would have followed a technical validation process of the CLEAN-ROADS system, thus limiting the amount of available time for this crucial assessment.

The report is structured as follows. Chapter 2 presents the peculiarities of the case study road, the winter maintenance operations that are actually carried out, and finally motivates the decisions concerning the selection of the position of the first roadside road weather station. Moreover, this chapter includes some references to the preparatory activities carried out for kicking-off the environmental ex-ante evaluation, organized as a function of the recommendations and instructions provided in the initial impact assessment [1]. Chapter 3 presents the results of the preparation activities carried out in correspondence of the first winter season during the project life time (season 2012/2013). In particular, an overview of the manual data collection process carried out in strong synergy with the road operators staff which has been organized in order to deeply evaluate the local state-of-art concerning winter road maintenance operations is given. This chapter presents the installation activities of the first roadside station in Cadino carried out in spring 2013 as well, and the initial environmental monitoring experiments on the component water. Finally, Chapter 4 describes the preparation activities that have been organized for the data collection campaign organized during the second winter season 2013/2014. The new IT system called “Trackoid” which has been introduced for the automatic collection of the data related to the winter road treatments details is explained, and the additional installation activities at the Cadino test site are presented, with a particular emphasis on the run-off collection and monitoring station which has been placed in order to initially evaluate the impact of salting activities on the component water.

2. Data collection campaign preparation

The preparation of the data collection campaign has been carried out with the main intention to maximize the amount of baseline data which is in the condition to allow an in-depth and quantitative analysis of:

- the peculiarities of the **winter road maintenance operations**;
- the **road-weather patterns** concerning the case study road;
- the local **environmental impact** produced by the winter road maintenance operations.

2.1 Case study road

The road which is considered in the demonstration activities of CLEAN-ROADS is a stretch of route SS12, which connects the local villages Lavis and Salorno (Figure 1). The length of the road is about 18 [km].

Figure 1: The case study road.

The motivations beyond the decision to consider exactly this route as test site for the advanced RWIS system are mainly the following:

- being the main state highway connecting the Province of Bolzano to the Province of Trento, the route is characterized by **significant traffic flows**, as illustrated in Figure 2. On average, about 6.700 vehicles travel every day on this route. A significant percentage of vehicles are **heavy vehicles**, as illustrated in Figure 3. During working days, the coefficient of heavy vehicles is on average about 16-17%, which means that about one thousand of heavy vehicles circulate every day over this route. This test site is located in one of the points of the regional road network where the heavy traffic component is more relevant [2]. For this reason, it is of primary importance to guarantee for this road a high level of service in terms of road maintenance during the whole year, in particular during the winter season, in order to maximize (i) road safety and (ii) traffic capacity. As far as local **traffic congestion events** are concerned, they are very unlikely to characterize this road section. The scatterplot illustrated in Figure 4 reveals that in the worst case less than the 5% of all transit vehicles are driving in correspondence of this detection point at a speed which is lower than 60 [km/h] (denoted as "**low speed vehicles**"), giving that the maximum speed admitted by law on that route is 90 [km/h]. This quantity arrives up to 20% in the case the reference threshold is increased up to 70 [km/h]. Figure 5 finally reveals that the amount of low-speed vehicles (considered in this case with a reference threshold speed of 70 [km/h]) slightly increase with the **amount of detected precipitation**, as a demonstration that these meteorological events are only one of a different set of parameters influencing traffic demand and vehicles speed patterns, with a contribution which can be estimated in the order of less than 5% of the entire vehicle population;

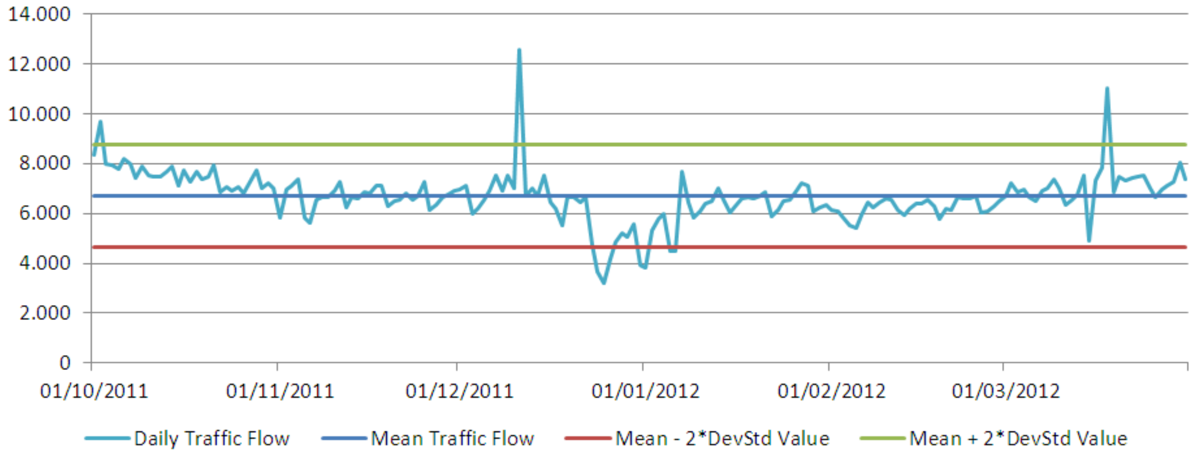

Figure 2: The total traffic levels in correspondence of the town of Salorno, in the period 01/10/2011 – 31/03/2012.

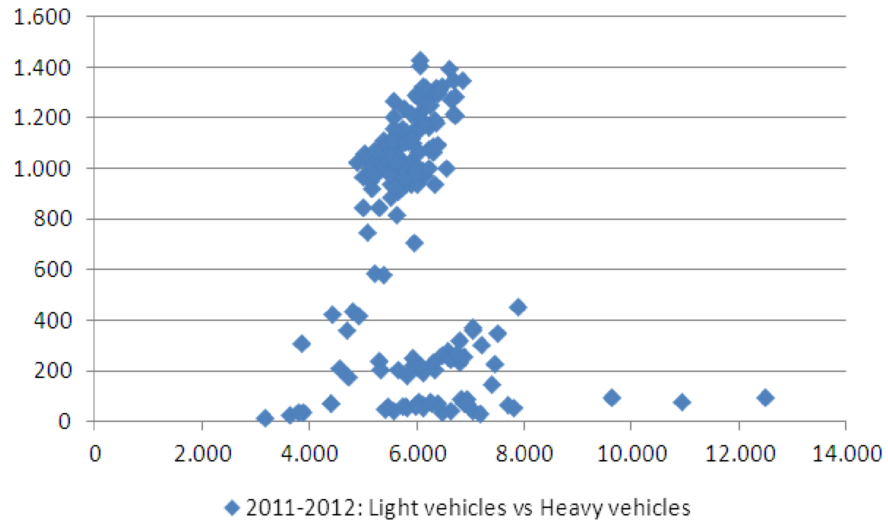

Figure 3: The scatterplot of heavy and light vehicles in the traffic monitoring point of Salorno.

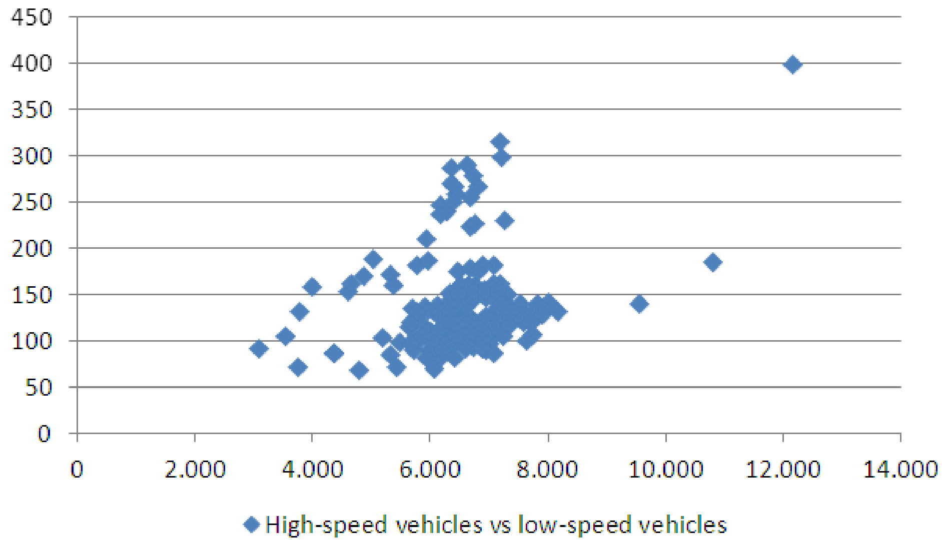

Figure 4: The scatterplot of high-speed and low-speed vehicles in the traffic monitoring point of Salorno (with low speed vehicles classified as those vehicles traveling at speed lower than 60 [km/h]).

- **the possible gain in terms of winter maintenance procedures optimization is expected to be higher for roads located in the valley bottom**, and less for roads located at higher altitudes. Previous experiences carried out by the Province of Trento in the past years have in fact demonstrated that the application of these kind of methodologies in the mountain areas of the region have a cost/benefit which is very small, and do not justify the cost for the maintenance of such a decision support system. Moreover, these systems are likely to generate false alarms during the pre/post winter season, if not properly calibrated. On the contrary, the optimization gain which can be achieved for roads at the valley bottom can be significantly higher, since the treatments could be oversized in order to avoid any kind of problems concerning winter road safety, being the traffic flows so intense;

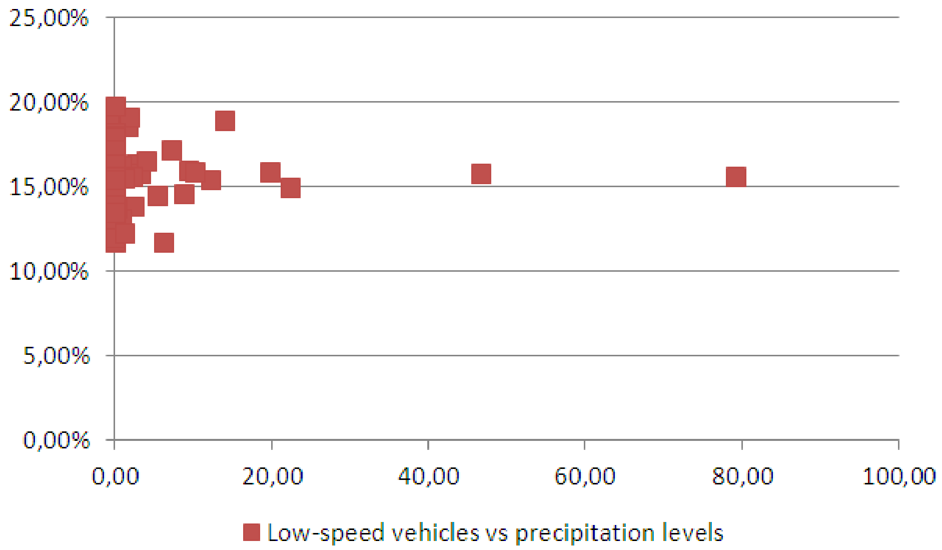

Figure 5: The scatterplot of precipitation levels and low-speed vehicles in the traffic monitoring point of Salorno (with low speed vehicles classified as those vehicles traveling at speed lower than 70 [km/h]and indicated in percentage terms with respect to the whole vehicle population).

- the test route is severely affected by **geographical parameters**, in particular by (i) topography and (ii) sky-view factor. In particular, the topographical environment is likely to produce frost hollows during cold, clear and dry nights, and to significantly limit the amount of solar radiation encountering the road – this phenomenon is more intense in the north part of the road, as deducible from Figure 1;

- the test route is the optimal choice from an **organizational point of view**, since it's located approximately halfway between the headquarters of partners located in the Province of Trento and in Province of Bolzano. This will significantly reduce the time, costs, vehicles kilometers traveled and consequent environmental impact of installation and maintenance activities of employees involved in the project.

As far as the meteorological characteristics of the test route are concerned, they can be initially deduced by considering the data illustrated in Figure 7, Figure 8 and Figure 9. The data refer to the winter season 2011 – 2012 (in particular, the period 01/10/2011 – 31/03/2012) and were collected by a weather station owned by the Province of Bolzano in correspondence of the town of Salorno, i.e. in the north part of the test route where the boundary between Province of Bolzano and Province of Trento is located (Figure 6).

The plots show in particular two main peculiarities of this specific road section, namely:

- its ability to reach **quite cold air temperatures (which can be significantly lower than 0[°C])** , as a consequence of the particular topographical environment;

- the limited amount of **winter precipitation**, which is however an aspect that can be significantly change among different winter seasons.

Figure 6: The position of the weather station managed by the Province of Bolzano within the case study road.

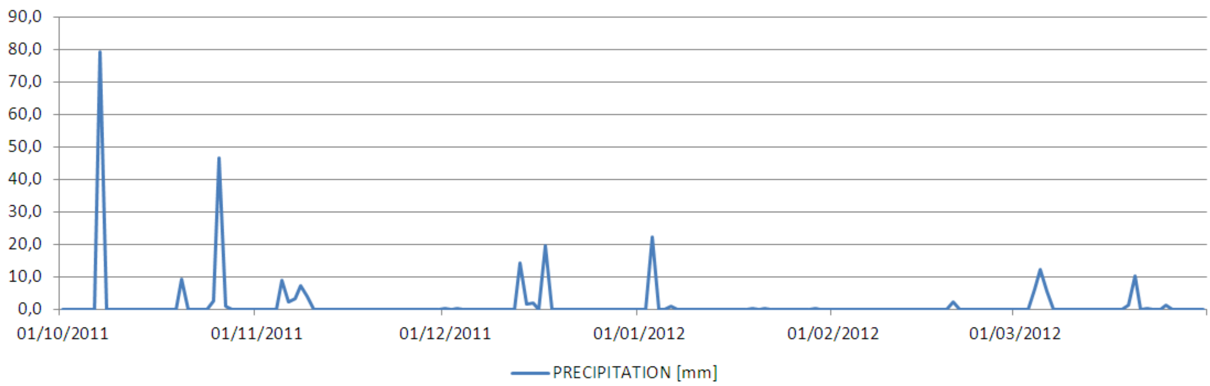

Figure 7: The daily precipitation levels in winter season 2011/2012 detected by the weather station in Salorno.

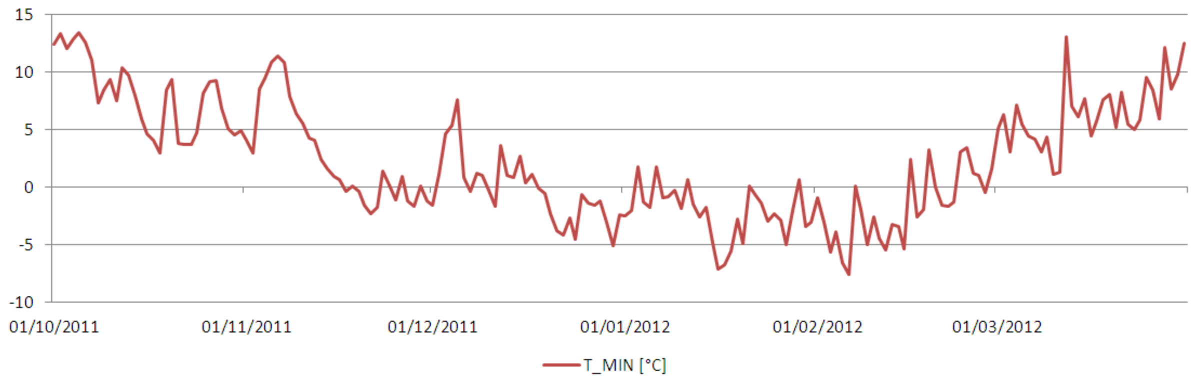

Figure 8: The daily minimum air temperature in winter season 2011/2012 detected by the weather station in Salorno.

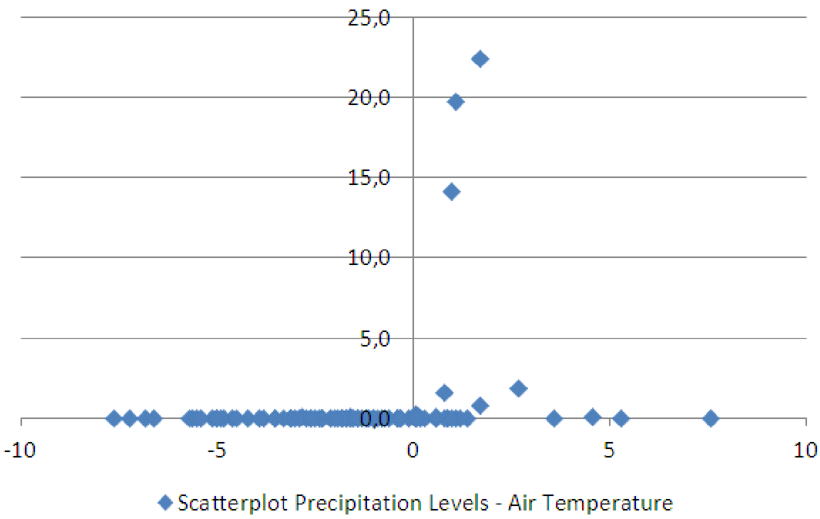

Figure 9: The daily precipitation levels and minimum air temperature scatterplot related to winter season 2011/2012.

The coordinator of the road operators team responsible of the winter road maintenance in this road stretch has moreover revealed that from their empirical experience, gathered in years of work over the target area, the road surface temperature profile is not uniform from a spatial point of view, and can significantly vary as a function of the current meteorological conditions. In particular, two **empirical cold hotspots** have been noticed within the case study road (Figure 12), one very near to a Variable Message Sign installed in correspondence of the small town of Cadino (Figure 10), and one located in correspondence of the boundary line with the Province of Bolzano (Figure 11).

Figure 10: Cold hotspot n.1 – south to the small town of Cadino.

Figure 11: Cold hotspot n.2 – south to the boundary line with the Province of Bolzano.

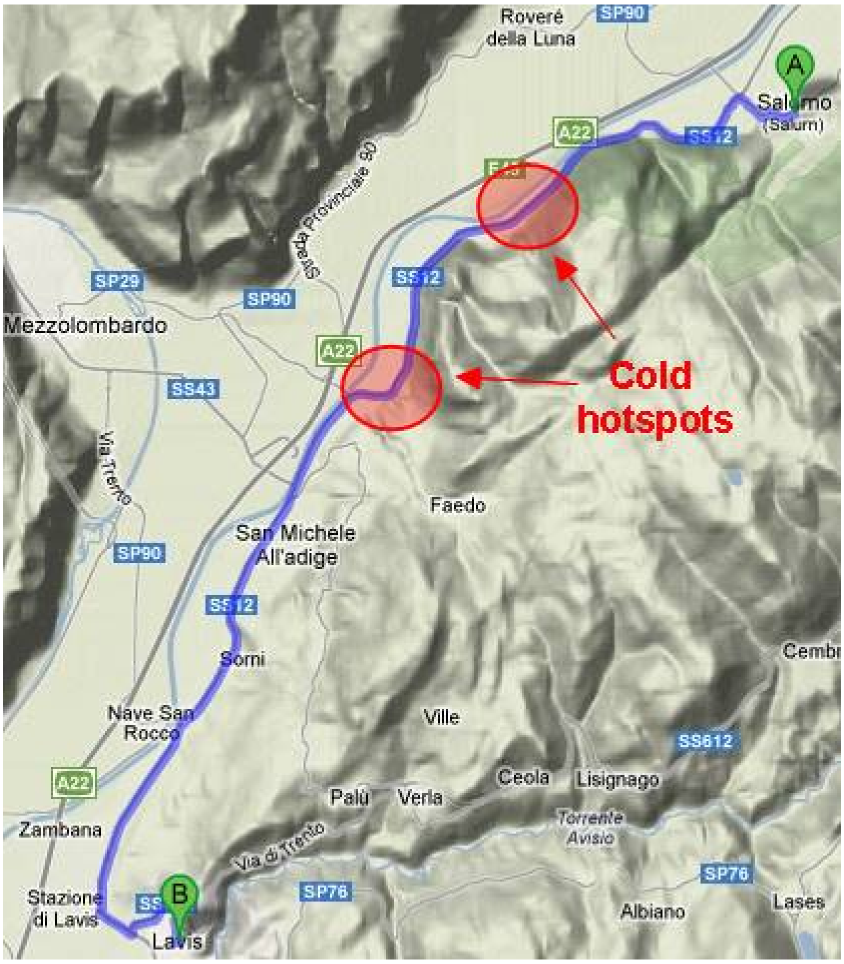

Figure 12: The position of the cold hotspots within the case study road.

2.2 Winter road maintenance operations

The operations of winter road maintenance are in general carried out in the period October – March. This period is however typically shorter for the case study scenario, since temperatures start to reach critical values only in correspondence of the second half of the month of November (as it is possible to assess in Figure 8). During this period, the road operators team activate the required availability so that they can promptly treat the road in order to maximize road safety conditions.

The **standard procedure** is that on around 04:30-05:00 in the morning the road operators always start a reconnaissance mission in order to effectively check the conditions of the competence road and to eventually treat it accordingly. The treatments are typically preliminarily arranged with the team coordinator, and are based on prior evaluation of the available meteorological bulletins (in particular the ones provided by the Weather Service of the Province of Trento). Specific and located phenomena could be identified during this work, and the road operator on the maintenance vehicle has the possibility to adapt the arranged the treatment as a function of these punctual conditions of the road (e.g. in correspondence of the aforementioned cold spots).

Special attention is given to **extraordinary meteorological events**, for example snowfalls. In this case, a road operator checks, even at night, the movement of the weather front. In case of night, he gives an alert to his colleagues and the pre-treatment and/or snow removal operations are activated under the supervision of the team coordinator. In these circumstances, a second daily treatment is typically applied on the road (i.e. not only the standard one in the early morning, but also in the evening, in order to minimize the ice formation risks). This increased treatment level continues until the road returns again in a satisfactory dry condition.

Within this road stretch, treatments are typically carried out with sodium chloride. Only in very specific circumstances other chlorides are used, e.g. if temperatures reach very low values, but its use is generally very limited because these substances are very abrasive and have shown to have significant corrosion effects on the road infrastructure as well as on the vehicles. Sodium chloride is applied to the road in dry form – a method which is different for example from the Province of Bolzano, in which salt is first pre-humidified.

The treatments are carried with proper salt trucks, and the salt recharging operations are carried out through a silos in correspondence of the local road inspector's house, the reference headquarter of the road operators team and where all main decisions and coordination activities are planned (Figure 13). The road inspector's house is located very near to the town of Lavis, slightly in the north of it.

As far as road treatments regulation is concerned, the salt trucks have installed on board an automatic salt spreader, which the road operators while driving can dynamically set up (Figure 15). Two main parameters can be controlled and changed through proper regulation mechanism:

Figure 13: The silos for the salt recharging operations for the salt trucks and the reference road's inspector house for the case study road.

- the **amount of salt flux** which is used is spread on the road; typical quantities are:
    - 5 [g/m2] – minimal quantity;
    - 15 [g/m2] – typical choice in case of snowfalls;
    - up to 40 [g/m2] which is the maximum supported value and practically never used (despite some very critical and specific circumstance);
- the **width of the spreading operation**, which is proportional to the amount of salt used in the time unit (Figure 14).

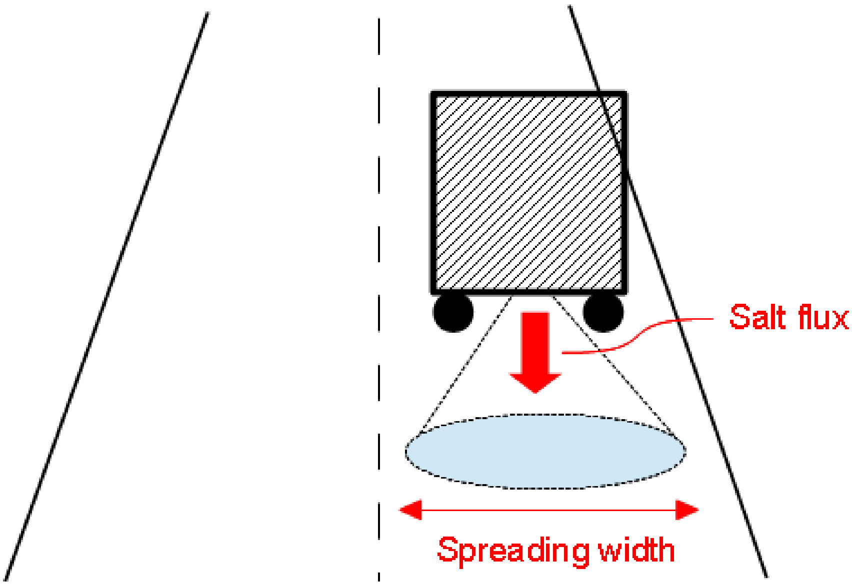

Figure 14: A simple representation of the coupe of parameters determining road treatments operations.

Figure 15: A salt truck and the on-board regulation mechanism for the salt spreading operations.

2.3 Test site selection

Given the preliminary decisions and considerations already stated in the introduction, the effort of project beneficiaries was concentrated on the identification of a suitable test monitoring site in correspondence of which the first static RWIS station as well as the equipment for the environmental impact evaluation would have been installed.

A first survey was organized immediately at the project start and held on September 7th 2012 (Figure 16). All project beneficiaries attended this survey, including meteorological experts from the Weather Service and laboratory technicians from the Local Agency for the Environment of the Province of Trento. The limited time availability for properly activating this site determined the choice to organize this survey even before the Plenary Kick-Off Meeting of the project, which was subsequently held on September 17th 2012.

On top of the aforementioned limitations, in particular the limited availability of power supply, the decision was to install this first static monitoring point in correspondence of a Variable Message Sign located in the target area, very near to the town of Cadino (Figure 17). Further advantages related to this choice were:

- the full control of the site by the Road Management Service;

Figure 16: Preliminary survey on the case study road.

Figure 17: The Variable Message Sign in correspondence of which it was decided to activate the first static monitoring point.

- the possibility to immediately activate infrastructure works, without any request of authorizations related to the use of private terrains;

- the possibility to quickly activate the static monitoring point;

- the space availability necessary for all reference sensors and equipment;

- the possibility to install a large variety of sensors, and to make in perspective preliminary test of novel sensing technologies;

- the possibility to detect road and traffic conditions in a non-invasive way through the above portal.

The list of road-weather parameters were defined by primarily taken in considerations the indications of the meteorological experts from the Weather Service of the Province of Trento, since these will represent the input parameters for the road weather elaboration and forecast models of the overall CLEAN-ROADS system. All the technical details concerning this first static RWIS station are available in deliverable D.A1.1 [3].

As far the environmental monitoring activities are concerned, it was immediately decided to install a roadside air pollution monitoring system near the road weather station. In this way, Action C2 would have been in the condition to evaluate the environmental impact of the project on component "air", by simply measuring, following standard methodologies and measurement techniques, the concentration of air pollutants at roadside level and correlate them with the winter road maintenance operations, and the traffic and meteorological conditions.

The evaluation of the environmental impact on component "water" has revealed to be on the contrary more challenging than expected. The original plan was to focus this set of activities by evaluating the impact of winter road treatments on controlled aquatic wildlife. Unfortunately, the survey did not reveal the presence of a suitable environment where to carry out this kind of monitoring activities. The only aquatic systems which were found revealed to be:

- **standing water streams**, flowing parallel to the road section, and very high probability to freeze during the winter season (Figure 18);

- **larger water streams**, which can be however not fully controlled and whose chloride concentrations be significantly influenced by the activities performed in the north part of it, and e.g. be influenced more by the winter road maintenance operations carried out by the road management service of the Province of Bolzano, and therefore with the actual risk to get completely unreliable results.

Figure 18: One of the existing static water stream near the case study road.

The decision was therefore to organize a different activity which could satisfy nevertheless the requirement to assess the environmental impact of the road salting operations and to determine the environmental gain to be related to the introduction of the CLEAN-ROADS system. These assessed limitation led to the plan, probably less ambitious than the original one, to perform these monitoring activities by evaluating the **chloride concentrations of run-off water streams**, properly collected from a specific section of the road infrastructure. This run-off water streams collection and monitoring system would have been installed in correspondence of the already identified detections site, with the further idea to possibly make some considerations also on the environmental impact on component "soil" by analyzing some ground samples located in correspondence of the road infrastructure. These statements can however be consolidated after performing an initial empirical campaign, in order to more specifically assess the potential and the relevance of this kind of analysis, since all these aspects must be targeted through unstandardized and unconventional monitoring methodologies.

3. Preparatory actions for winter season 2012/2013 campaign

The data collection campaign preparation process finally lead to the activation of the monitoring activities for the winter season 2012-2013. As already illustrated in the introduction of this report, the bureaucratic delays inside the Province of Trento concerning the approval of the external expenditures did not allow to activate the first static monitoring station in time for being used during this first winter season. For this reason, it has not been possible to acquire a first empirical dataset of road weather patterns, air quality levels and chloride concentrations of run-off waters.

A **recovery plan** able to guarantee the achievability of project's objectives was therefore immediately identified in order to properly complete the preparatory studies of Action A1 and the ex-ante environmental monitoring activities of Action C2 during the following winter season (2013-2014), and all this by (i) minimizing the impact on other correlated project actions (e.g. implementation action bundle B), (ii) possibly increasing the overall effectiveness and the impact of the project actions, and (iii) satisfying the initial time and budget constraints. The reference plan is presented in detail in the Inception Report [4] and reported in its most important parts in the introduction of this report.

In lights of these critical issues and the following revised plan, the contents of this chapter must be read in the following way:

- the information related to the **activation of the first static monitoring site** refer to the competition of the data collection campaign which will take place in the winter season 2013/2014;

- the information related to the **empirical data related to the treatments performed by the road operators** are going to be used within the initial phase of Task A1.3, where a correlation with available and correspondent traffic and meteorological data is going to be performed.

3.1 Monitoring station installation

The works of installation of the first static monitoring site were finally carried out between March and April 2013, in cooperation between the technical staff of Famas System (for the road weather equipment) and the Local Agency for the Environmental (for the air quality monitoring station), and all this under the coordination of the Road Management Service of the Province of Trento. Figure 19 presents the main components of the monitoring site, without entering into the technical features of all the different devices and sensors (since they are already covered by deliverable D.A1.1). It is composed by (i) a **road-weather station**, which is equipped with meteorological sensors and detectors for measuring the conditions of the road; (ii) an **air quality monitoring station**, composed by air pollutants concentrations sensors installed over a container in which other useful connectors and instrumentation are located; and (iii) the already existing **portal on the Variable Message Signs**, where the non-invasive traffic detectors are going to be positioned. It is worth noting that in light of the incurred delays, the latter detectors have not been installed yet, but will be activated very soon during the summer season, when all site will be activated in order to check the proper functioning of all installed equipment and devices.

Figure 19: The first static monitoring site.

The installation works took the necessity to reduce for a limited amount of time the traffic capacity of the road (Figure 20). This was necessary in particular to guarantee the installation of the sensors for the detection of the road surface temperature, which are located in different crossing points of the section in order to evaluate how this parameter varies as a function of distance from the side of the roadway (Figure 21).

It is worth noting that before placing the road-weather station and the air quality monitoring station, two plinths were previously designed and positioned at their base. As an example, the design drawing concerning the road-weather station plinth is annexed to the present report.

Figure 20: The road works organized during the installation of the first static monitoring site.

Figure 21: The positioning of the invasive sensors inside the road in correspondence of the first static monitoring site.

At the end of this installation phase, which comprehensively took no more than a couple of weeks, a notice board was installed on a side of the air quality monitoring station container. The actual configuration of the first monitoring site is presented in Figure 22.

Figure 22: The actual configuration of the first static monitoring site.

As far as the run-off collection and monitoring system is concerned, once the project beneficiaries realized that it wasn’t possible to activate the monitoring site in time for being used during the winter season 2012/2013, they took the decision to not immediately install this component. This decision was also motivated in light of the challenging aspects described in the previous chapter, which revealed to be more complex than expected, since further surveys carried out during rainy days revealed the absence of natural aggregation points of run-off waters, and thus the necessity to carefully design the way these water can be effectively collected (Figure 23).

For this reason, the Technical Supervisory Board took the important decision to take advantage of this delay related to the ex-ante environmental monitoring activity in order to get more details and background information on how this monitoring technique was implemented. The chance revealed to be a complementary experimental initiative carried out by the University of Trento (and more specifically the Civil Environmental Engineering Department) in cooperation of other services inside the Province of Trento. More specifically, a run-off collection and monitoring station was installed in correspondence of the road infrastructure near the lake of Caldonazzo, with the purpose to scientifically investigate current methodologies for the collection and characterization of run-off waters (Figure 24).

Figure 23: The case study road during an intense rainy day.

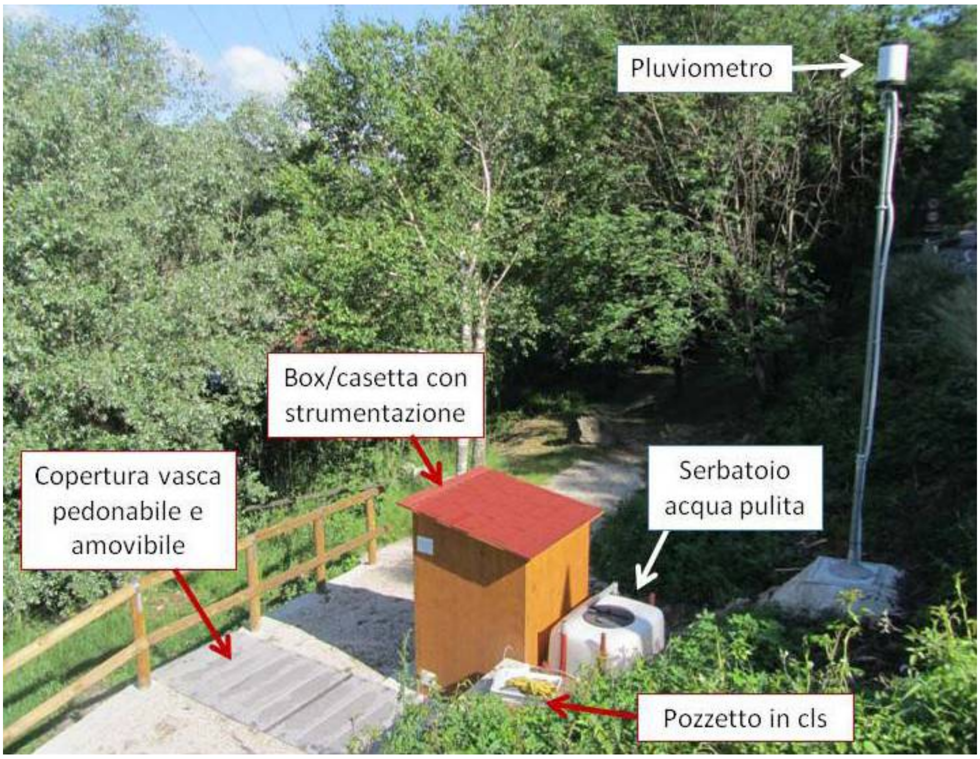

Figure 24: The run-off waters collection and monitoring system installed by the University of Trento in correspondence of the lake of Caldonazzo [5].

The main components of this monitoring station are:

- a **present-weather sensor**, which detects the amount of precipitation fallen on the road (this information will be actually covered by the road weather station);

- a **small (existing) water well**, in which run-off waters are collected;
- a **water tank with two spillways**, in which run-off waters available in the water well are merged.
- a box containing various **instruments for the characterization of the collected waters** (e.g. chloride concentration sensors);
- a **holding tank for the conservation of clean water**, to be used for the periodical of the cleaning operations of the water tank and for maintaining constant its level.

Since the CLEAN-ROADS system is not going to be demonstrated outside the SS12, it was not decided to record the operations of the winter road maintenance activities in this area, because any possible measure would have been useless if then not compared with others collected after the activation of the CLEAN-ROADS system (ex-ante / ex-post approach). For this reason, the project beneficiaries and in particular the Local Agency for the Environment of the Province of Trento decided just to initially and externally study and evaluate this possible monitoring approach, and **determine the technical feasibility to reproduce it in a proper point within the case study road**.

These activities are actually on-going and have exactly the objective to perform a similar monitoring activity on component "water" inside the test area through a similar methodology, which must obviously be scaled and adapted for this different environment. The plan is to activate such a station before the winter season 2013/2014, in occasion of which the ex-ante monitoring campaign will be carried out.

3.2 Road management operators activities monitoring kick-off

Given all aforementioned limitations concerning the first winter season of the project, the main focus was necessarily put on the collection of a detailed dataset related to the activities of road operators responsible for the winter maintenance operations on the SS12.

This collection campaign was coordinated directly by the Road Management Service, and organized in cooperation with the coordinator of the road operators team. The staff was requested to constantly record the information related to the treatments they actually did, in particular:

- the **treatment reason** (ice prevention, before / after a snowfall);
- the **initial configuration of the chosen treatment operation** (salt flow and width);
- the **actual configuration of the treatment operation in correspondence of the monitoring site**, so to allow a direct and more specific correlation with field data collected by the static RWIS sensors.

The data reporting template which was used in this data collection campaign is presented in Figure 25.

MESE DI ______________________ ANNO_______________

SS 12 dell'Abetone - Brennero CLORURO DI SODIO

Data	Ora	H neve cm	TIPO TRATTAMENTI				Tratta LAVIS - SALORNO					Al km 398,000			
			Bagnata anti ghiaccio	Preventivo neve	nevicata in corso	post nevicata	km 386,400-401,300				Quantità q.li				
							g/m^2	larg./m	Andata	Ritorno		g/m^2	larg./m	Andata	Ritorno

Figure 25: The data reporting template used by road operators in order to record the information concerning their winter road maintenance activities.

The recording activities covered the whole winter season, and were only limited to those days in which a certain treatment revealed to be necessary. The meteorological conditions occurred during winter season 2012-2013 determined a necessity for quite intense treatments operations in December 2012 and January 2013, with little activities experimented in February and March 2013. This data is currently under evaluation phase and the results of this preliminary studies will be reported in D.A1.3 [6].

4. Preparatory actions for winter season 2013/2014 campaign

4.1 Monitoring station enhancement

The monitoring capabilities of the first static monitoring site were significantly improved during 2013. Additional road weather sensors were installed, a complex system for the collection and monitoring of runoff waters was introduced, and an automatic tracking tool was given to road operators in order to improve the quality and the amount of information related to road treatments. The details of such additional preparatory actions are presented in the following paragraphs, respectively.

4.1.1 Air and Road Sub Surface Temperature Sensors

Other two measurement gauges were installed before the winter 2013/2014 campaign.

The first one is a **ventilated air temperature probe**, installed just next to the other temperature gauge (Figure 26). This duplication of sensors has been introduced with the purpose to investigate more in detail the accuracy and the response delay of the existing air temperature probe. This necessity emerged during winter season 2012/2013, in which a couple of unclear measurement patterns were observed.

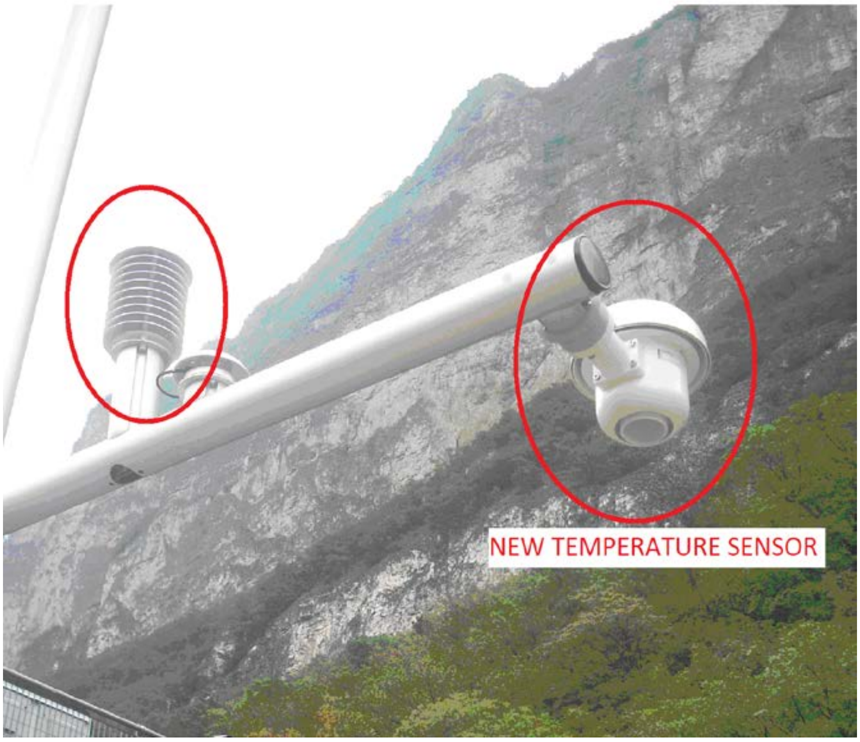

Figure 26: New ventilated temperature sensor (right side) next to the existing air temperature probe.

The other **temperature probe** was placed **40 centimetres under the road surface**. This additional sensing unit was mainly introduced in order to be able to collect input data for one of the road forecasting models that the project is currently testing in this local road environment, i.e. METRo [7]. Road subsurface measurements offer moreover the possibility to investigate in more details the thermal inertia of the ground, in particular in correspondence of sharp deviations in the meteorological conditions. By comparing such measurements with others taken at different sites (e.g. suspended roads like viaducts and bridges) it will be possible to better characterize the thermal properties of different road layers types. Two different sub-surface sensors were installed: one under the paved road surface, and one under the sideway ground, slightly outside from the paved surface.

Technical details of the new measurement gauged are reported in the updated version of D.A1.1 [2].

4.1.2 Runoff water collection and monitoring

To evaluate the impact of salting activities on the water component a run-off collection and monitoring station was placed next to the air quality and road weather ones. The monitoring campaign during the winter time involved rainfall measurements, run-off waters flow-rate estimations, and collection of a significant number of samples and analyses of various contaminants.

The main elements of the run-off monitoring station (including infrastructure ones) that has been installed are:

- **40 meters of gutters (an open concrete channel)** at roadside to collect the run-off;

Figure 27: Runoff water collection and monitoring system - concrete gutters at roadside.

- a **water storage with two spillways** in which run-off waters are collected and where the first analysis are performed;

Figure 28: Runoff water collection and monitoring system - water tank.

- a **rain gauge** for in-situ measurements of natural rainfall;

Figure 29: Runoff water collection and monitoring system - rain gauge.

- a **temperature, turbidity and conductivity sensors** installed on a funnel where the run-off waters are conveyed and a **flowmeter** inside the tank;

Figure 30: Runoff water collection and monitoring system - sensors for in-situ monitoring of water quality.

- **an adjacent structure** where an automatic sampler and the other monitoring and transmission equipment are located.

Figure 31: Runoff water collection and monitoring system - automatic sampler and electronic instrumentation to record and transmit data.

Technical details about measuring instrumentation are reported in the updated version of D.A1.1.

Road operators visited the run-off waters monitoring systems every two weeks for routine maintenance of the instrumentation, while the samples automatically collected were immediately taken for further laboratory analysis.

4.2 Road management operators activities monitoring enhancement

During the first project winter season campaign (2012/2013) several recording errors or misunderstanding were noticed. These issues were not related to the negligence of road operators, but directly motivated by the manual procedure for the recording of road management activities. Moreover, the amount of information one can get with such a method is intrinsically limited, and does not offer sufficient possibilities for detailed correlation analysis, e.g. with the road weather station measurements.

For this reason, a new automatic system was gradually introduced in the second winter season. In order to accomplish this task, a simple activities' tracking solution called **trackoid**, developed by a local environmental engineering society, **HydroloGIS**, and still in pre-deployment phase has been used. trackoid is mainly an extremely simple application running on Android mobile devices for automatically tracking and geo-locating working operations. This solution is particularly interesting for recording maintenance activities, for example those carried out on the road infrastructure. In the scope of the project, the aim has been to use trackoid in order to register the details of each winter road maintenance activity on the case study road.

Three mobile devices, one for each operating truck, were entrusted to the involved operators' team. Several meetings were organized in preparation of the winter season 2013/2014 in order properly introduce this tool and explain the motivations beyond its usage. A complete how-to was moreover prepared and put at their disposal in case of any technical doubts (Figure 32). Frequent additional meeting and phone calls were organized during the winter period in order to continuously support them in the proper use of the tracking.

4.2.1 trackoid – tracking smartphone application

From the user's perspective, the application has been simplified at the highest level. Road operators have just to insert a couple of information related to the nature of treatment he is going to manage; the rest of the tracking operations are autonomously under the control of the device. As indicated in the how-to, what the road operators have to do is to before starting an activity:

- switch on the smartphone;
- verify that GPS and 3G connection are not disabled;
- start the trackoid application and authenticate themselves (the credentials are the same for the whole team);
- open the map menu and activate the road operation;

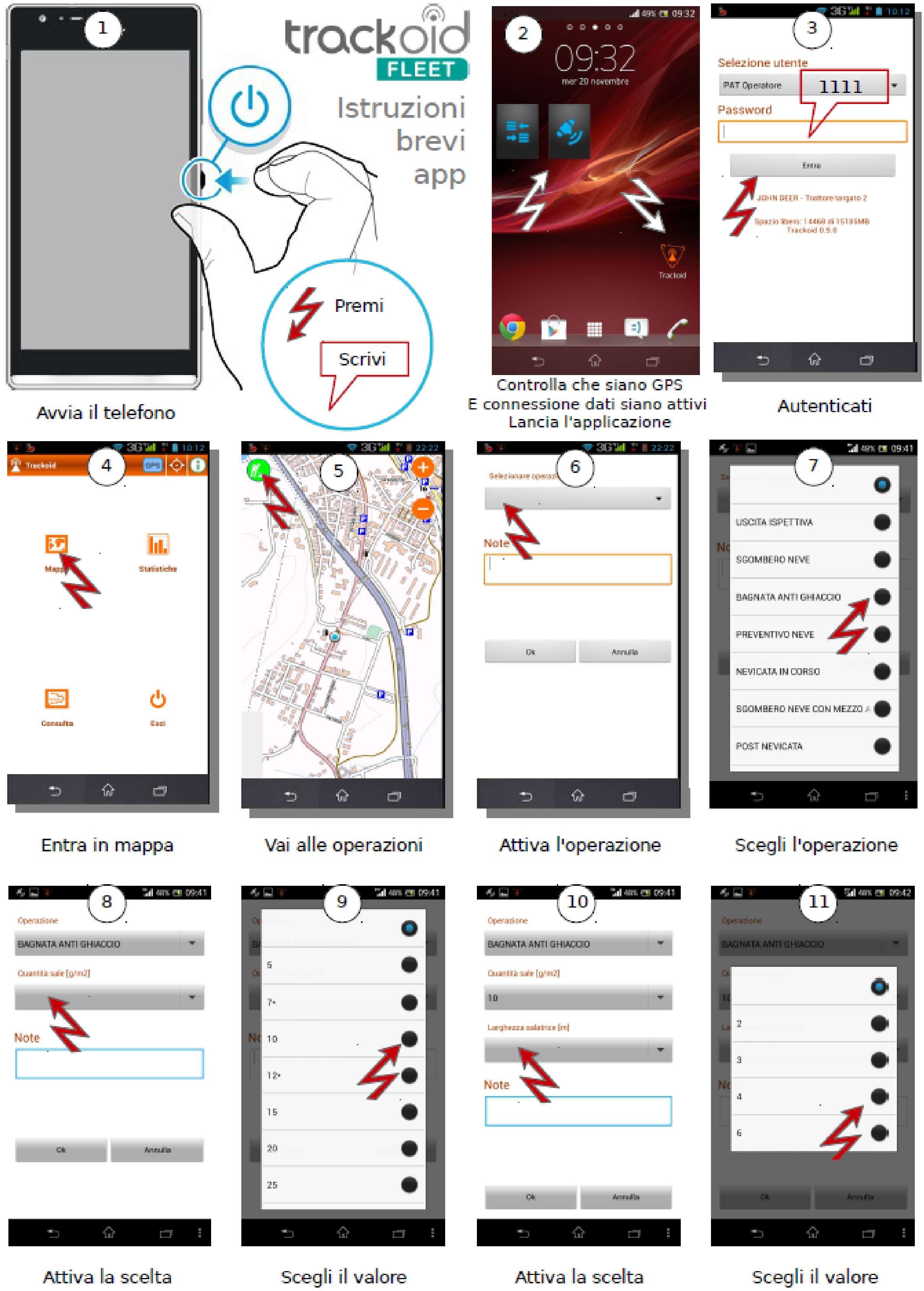

Figure 32: Trackoid how-to instruction sheet for road operators.

- configure the operation from a pre-complied menu:
  - type of treatment (available options are: road inspection; snow removal; anti-icing treatment; preventive treatment before a snowfall; snowfall in progress; post snowfall);
  - spreading details (amount of salt flux and width of the spreading operation);
  - other additional notes (e.g. damages to private and public properties);
- confirm the start of the operation;

At the end of the activity, road operators have only to close the operation and then the application.

4.2.2 trackoid – analytics web application

As already underlined, the introduction of trackoid not only simplifies recording activities requested to road operators, but also provides automatically and on a real-time basis detailed information related to the winter road activities. In order to accomplish this, geo-located data collected by smartphone applications is automatically delivered on a real-time basis to a back-end server.

All this information can be checked by project staff through a web application, where all statistical information related to each recorded treatment can be analyzed, even on a GIS support (Figure 33 and Figure 34).

4.2.3 Lessons learnt

The use of this empirical system by the road management operators' team during the winter 2013/2014, didn't present relevant trouble or issues. The introduction of this technological novelty has been accepted with favor and interest, and no privacy concern was put in evidence. This result was also possible in light of the intense involvement process of this team, which started immediately at the project's start and put the conditions to avoid any issues of reception of the new solutions trialed in CLEAN-ROADS. More detailed information about the involvement activities of this target are reported in D.D2.8 [8].

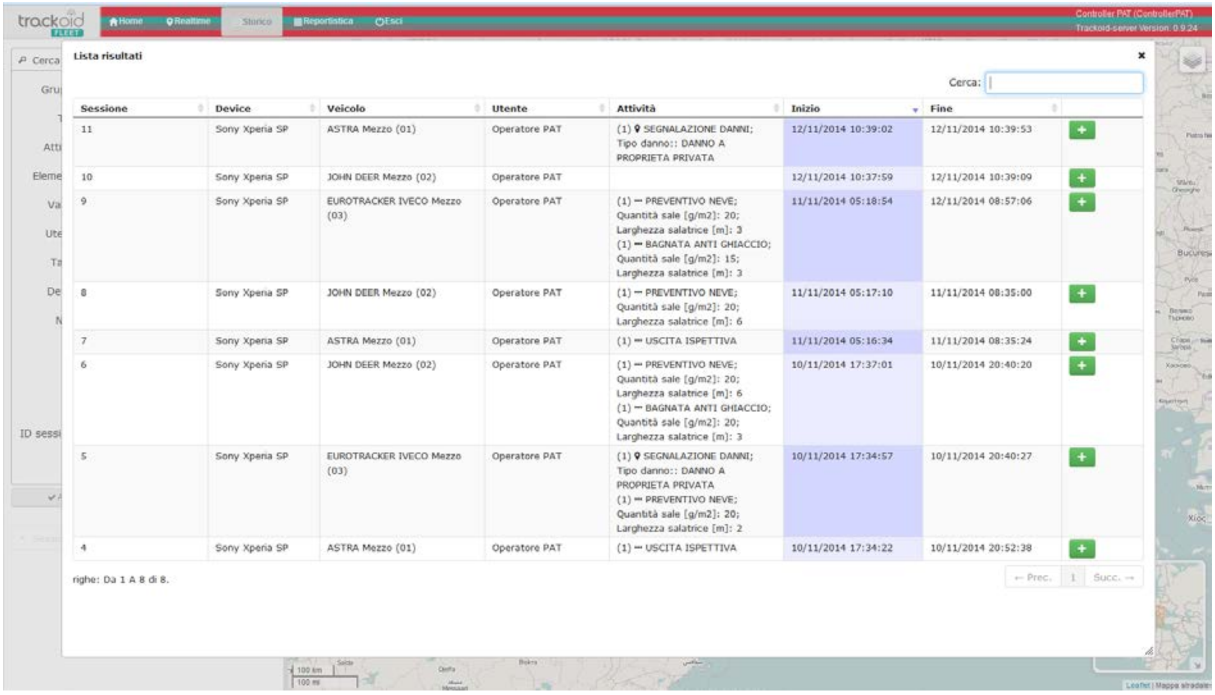

Figure 33: Trackoid analytics web application: historical data visualization.

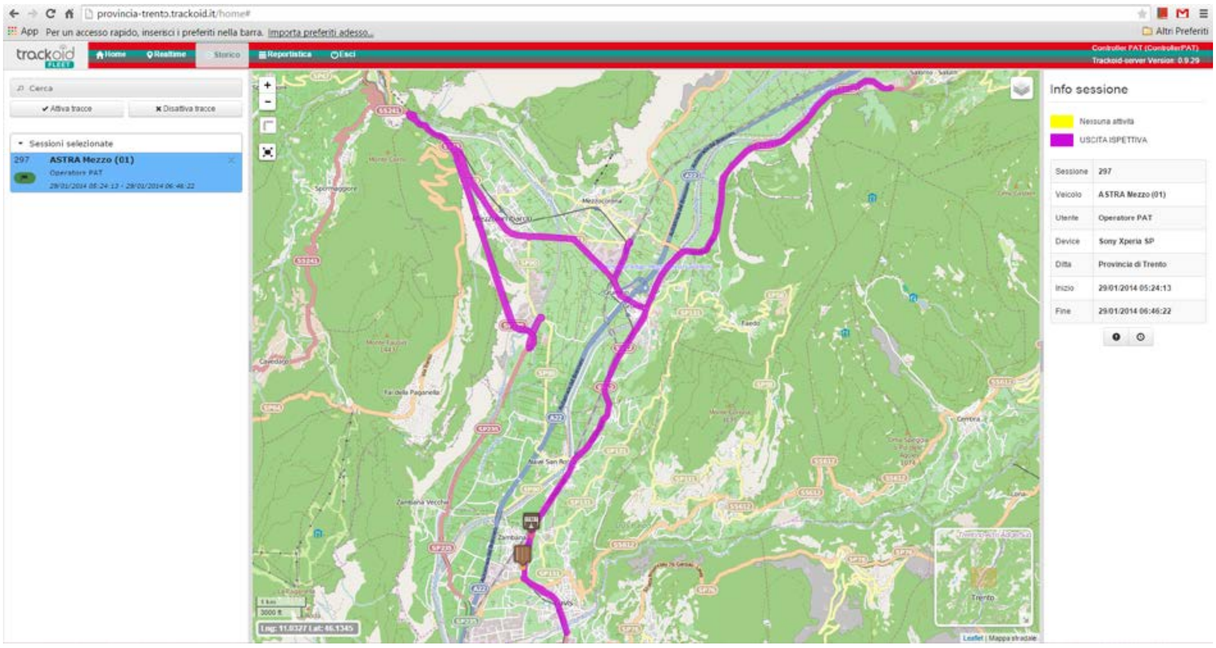

Figure 34: Trackoid analytics web application: single event geo-referenced visualization.

4.3 Thermal mapping sessions organization

During winter season 2013/2014, an additional data collection campaign was organized. As for the static RWIS station, in which the first prototype installed in Cadino has been empirically evaluated for determining the final design choices for the other RWIS stations to be installed before winter season 2014/2015, a first field operation test session was organized with the mobile RWIS station too. The purpose of this activity was on one side to empirically validate the sensing technology and assess the performance of the overall designed system, and on the other side to collect a first relevant set of spatialized road temperature data, to be used to quantitatively characterize the test route and appreciating spatial temperature variations during specific meteorological conditions. This set of data is of upmost importance for the project goals because of different reasons: on one side, one can have an additional support in the identification of relevant locations (e.g. cold hotspots) to be monitored through more precise static RWIS stations; on the other side, one can think to use this data to pre-calibrate complex 2D road weather models.

The mobile RWIS station prototype is characterized in particular by a set of infrared road temperature sensors, assembled in a very experimental way on a modified bicycle rack sited on the back side of the van. The choice of a homologated bicycle rack has been made in order to avoid any approval issues from the Driver & Vehicle Licensing Agency. As shown in Figure 35, three set of sensors has been used:

- the sensor on the right measures **eight different lateral temperatures at different heights**. In this way, the street side thermal print can be characterized with a very high precision;
- the sensor in the middle is going to be the **reference one for the CLEAN-ROADS system**; it is installed in this position in order to avoid the lifted water from wheels and the nearest as possible from the asphalt. The choice of the back side of the van has been made in order to protect the measurement system from atmospheric events;
- the third sensor, installed near the number plate of the van, is a commercial sensor which is used for control and comparison purposes.

For more technical details related to the mobile RWIS station prototype development process, please refer to deliverables D.B1.1 [9] and D.B2.2 [10].

Based on the above considerations, a variety of field test sessions has been organized, with the purpose to build a statistically strong ground truth in the highest number of boundary conditions, i.e.:

- **sessions during changing weather conditions**: essential for knowing how road behavior spatially changes under non-stationary meteorological conditions;
- **sessions at the same day time but in different days**: important for gathering a solid seasonal trend of the road temperature, to be related to air temperature and to thermal soil inertia;
- **24-hours sessions**: important for having a complete spatialized road signature at all day times;

- **session in the worst possible conditions (clear nights without wind)**: fundamental to check the highest road temperature variations that one can empirically verify in the case study road.

Figure 35: Mobile RWIS station prototype used during first field session activities during winter season 2013/2014.

Mobile RWIS station sessions were organized in strong cooperation of the road operators, who have had at disposal the test vehicle for the whole 2013/2014 winter season. Beneficiary Famas System, who has developed the prototype, was strongly involved in the organization of the first sessions and in the training of the road operators in the correct usage of the novel monitoring system. The cooperation was so strict and without issues that the last thermal mapping sessions were carried out by the road operators in full autonomy. Again, please refer to deliverable D.D2.8 for more details about the involvement of road operators.

In total, 31 thermal mapping sessions were performed. The complete list is reported in Table 2. For a complete evaluation of the empirical results obtained, please refer to deliverable D.B2.7 [11].

Session Nr.	Date	Starting Time
1	15/11/2014	11:26
2	06/12/2014	15:26
4	14/02/2014	00:47
5	14/02/2014	02:52
6	14/02/2014	04:57
7	14/02/2014	08:18
8	14/02/2014	08:28

9	14/02/2014	09:11
10	14/02/2014	10:57
11	14/02/2014	12:46
12	14/02/2014	14:10
13	14/02/2014	15:30
14	14/02/2014	16:52
15	14/02/2014	18:21
16	14/02/2014	20:54
17	14/02/2014	22:55
18	03/03/2014	05:18
19	04/03/2014	05:37
20	05/03/2014	05:48
21	06/03/2014	05:33
22	06/03/2014	06:01
23	07/03/2014	05:31
24	07/03/2014	19:29
25	07/03/2014	21:28
26	07/03/2014	23:05
27	10/03/2014	05:44
28	11/03/2014	05:54
29	11/03/2014	05:35
30	12/03/2014	05:25
31	24/02/2014	17:08
33	14/04/2014	18:13

Table 2: Complete set of thermal mapping sessions organized during the winter season 2013/2014.

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ANNEX 1: The final design of the plinth of the road weather station