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CLEAN-ROADS

Action A1:
Experimental data collection campaign during a winter season

D.A1.1

Static RWIS stations

Project Coordinating Beneficiary	Provincia di Trento (PAT)
Project Associated Beneficiary n.1	Famas System (FAM)
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Document history

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31/05/2013	Merler Giacomo (PAT), Ilaria Pretto (PAT), Roberto Cavaliere (TIS), Thomas Tschurtschenthaler (Famas)	Initial installation of the RWIS station positioned in the first months of 2013 in correspondence of the test site of Cadino.
31/05/2015	Giacomo Merler (PAT) Ilaria Pretto (PAT), Roberto Cavaliere (TIS), Thomas Tschurtschenthaler, Roberto Apolloni (Famas)	Final configuration of the RWIS station that has positioned in correspondence of the test site of Cadino, used to carry out the first complete data collection campaign during the winter season 2013/2014 (according to revised action plan for the winter seasons covered by the project).

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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

Action A1 is one of the two actions expected in the preparatory actions A, which is responsible for the installation of five RWIS (Road Weather Information System) stations in order to collect baseline data to be used to determine quantitatively the benefits and specifically the environmental gain produced by the optimization process that will be tested during the subsequent steps.

The RWIS stations are composed of:

- **atmospheric sensors** such as temperature, relative humidity, wind speed and direction, present and typology of precipitation;
- **temperature sensors** to measure the surface and sub-surface road temperature and to classify the road condition surface in terms of of dry, wet or frozen state;
- **sensors of salt presence** *and concentration* on the road surface.

The collected data will be then matched and analysed with other data coming from:

- meteorological forecasts and bulletins;
- winter road maintenance treatments;
- traffic data;
- environmental data, i.e. air pollution levels and chloride concentrations of run-off waters.

During the measurement campaign it will be evaluated the environmental impact produced by the intense use of salt and gravel on the roads with the aim of (i) comparing it with other reference scientific studies and (ii) estimating the local effects produced on surrounding aquatic systems and vegetation.

It is important to underline that the aim of this document is just to provide an accompanying document for the installed prototype (i.e. the first monitoring site), offering in a synthetic way the reference technical characteristics of its main components. The complete description of the reference monitoring technologies at the base of the different sensors is out of the scope of this document, and is offered through the deliverable D.A2.2 [1].

In light of the delays occurred during the preliminary stage of the project and the following recovery plan, it is worth to remember the different scope of this report with respect to the original project plan. The deliverable is indeed available in two versions. The first one, delivered together with the Inception Report, has presented the initial installation of the RWIS station that has positioned in the first months of 2013 in correspondence of the test site of Cadino. The second one, delivered together with the Mid-Term Report, has presented the final configuration of this RWIS station that has been used to carry out the first complete data collection campaign during the winter season 2013/2014 according to the revised action plan for the winter seasons covered by the project.

Before entering into the details of the technical aspects of the road weather station, it is finally important to recall the attention to relevant project’s aspects:

- the particular character of this installation, which has the capability to monitor not only the local road weather conditions but even the environmental impact on air and water systems of road salting activities. This will be indeed the only RWIS station installed in the project that will have this peculiarity;
- the decision to postpone the installation of the last four static RWIS stations foreseen in the project proposal before winter season 2014/2015, based on the empirical results and indications collected during the data collection campaign of the year before. For this purpose, the data collected during the thermal mapping sessions through the first mobile RWIS station prototype have been considered as well in order to understand the spatial variability of road conditions within the case study road. The technical specification of these latter four static RWIS stations are not covered in this report since they are illustrated in the prototype deliverable D.B2.1 [2];
- the limited scope of this document, which aims at providing a synthetic but exhaustive overview of the most relevant characteristics of this first project installation. More engineering details about the final configuration of all RWIS stations can indeed be found in deliverable D.B1.1 [3].

2 Road-weather station technical sheet

This chapter presents the road weather capabilities of the monitoring station installed at location Cadino, (WGS84 coordinates: 46,210154 N / 11,151913 E). Figure 1 shows the current configuration of the RWIS station; the pole on the left is the standard support for the atmospheric sensors.

Figure 1: Typical configuration of RWIS station.

On the top of the stick, at a height of 5 [m], the sensor for the measurement of the **precipitation intensity and type**, as well the **anemometer** and the **wind vane** (in charge of measuring the wind speed and direction, respectively) are placed (Figure 3). On the same structure (Figure 2), at a height of 2.5 meters, the devices responsible for the measurement of the **relative humidity** and **air temperature** as well as for the determination of **global radiation** (which is estimated by means of a pyranometer) are located.

Figure 3: Anemometer, wind vane and precipitation detector.

Figure 2: Pyranometer (left), thermometer and RH detector (right).

On the road, four equivalent invasive **road surface conditions sensors** measuring (i) the **temperature** of the first centimetres of the superficial layer and (ii) the **saturation level of the liquid film** on the surface are installed (Figure 4).

Figure 4: Sensors installed on the road surface

Finally, inside the main cabinet, on the upper left side, the **pressure meter** is located (Figure 5). All the raw data acquired from the different sensors are sent to a **data management unit** stored in this case (easily identifiable in the aforementioned picture) where it is collected, converted, elaborated and stored. This unit can be then connected through a dedicated **communication interface** in order to remotely send the data to a central storage system.

Figure 5: RWIS data management unit.

Figure 6: Air quality monitoring system.

The **air quality monitoring** system is actually an independent roadside unit installed on the roof of a separated container. The system is capable to evaluate the composition and quantity of **particulate matter** (PM_{10}), following standard methods and procedures which are used to determine the air quality concentrations requested by the national law (Figure 6).

2.1 Road weather monitoring station initial configuration

2.1.1 Data management unit

Figure 7: MROAD 500

This unit includes the reference technology used in the product **MROAD 500**, a commercial component capable of collecting, elaborating and storing data acquired by various sensors operating both in the weather and traffic monitoring [4]; images can be handled as well by means of an input of a webcam. Data and images can be sent at specific time intervals to a FTP server through the standard protocol TCP/IP.

Main features can be summarized as follows:

- control of traffic, weather and road surface conditions detectors;
- real-time statistical data output;
- high-communication capacity;
- low energy demand;

- compact and watertight package;
- internal memory: 2 [GBytes]
- compatible with both digital and analogical inputs;
- operating temperature -40… 80 [°C]
- operating system: Embedded Linux.

2.1.2 Air temperature and humidity sensors

This versatile probe, based on **Rotronic Hygroclip HC2** line series [5], is capable of measuring **relative humidity** (RH), **air temperature** and of indirectly calculating the **dew/frost point**. The HC2 probe measures relative humidity with a **capacitive sensor** (ROTRONIC Hygromer® IN1) and temperature with a **Pt100 resistance temperature detector** (RTD) [1].

Main features can be summarized as follows:

- RH accuracy at 23 [°C]: ±1.5%
- air temperature accuracy at 23 [°C]: ± 0.3 [°C]
- application temperature range -40…60 [°C]
- application relative humidity range 0…100 [%]
- programmable automatic sensor test with fail safe mode and sensor drift compensation
- long-term stability: <1 [% / year] / 0.1 [°C / year]
- response time: <15 [s]

Figure 8: Hygroclip HC2 line series

The sensor probe is mounted inside a **radiation shield** protecting the temperature and relative humidity sensor (Figure 2). The shield is characterized by multiple plates with common profile that can block direct and reflected solar radiation, but permits the normal air flow passage. In this way, errors that might be induced by solar radiation and precipitation can be properly avoided in advance. The plastic plate material ensures moreover high reflectivity, low thermal conductivity and maximum weather resistance.

The is mounted on a mast at about 2,5 [m] height, as recommended by WMO.

2.1.3 Atmospheric pressure sensors

This sensor, produced by **Lambrecht**, can measure the absolute pressure through a **piezoresistive pressure measuring** cell working in the range 800..1100 [hPa] [6]. The lower limit of this range can be reduced to 600 [hPa], but this possible adjustment was not considered being the RWIS station installed at a low altitude.

Main features can be summarized as follows:

- operating limits: 300 – 1375 [hPa]
- accuracy:
    - ±1 [hPa] (range -10…+60 [°C])
    - < ±2 [hPa] (range -20…+10 [°C]);
- resolution: 0.1 [hPa];
- range of application:
    - altitude: 0… 4000 [m]
    - temperature: -20…+70 [°C]
    - humidity: 0…99 [%]
- applicable with/ without data loggers in energy-saving mode (e. g. solar operation);
- operating temperature between -30°C and 60°C;

Figure 9: Atmospheric pressure sensor.

As there is no need to have this sensor mounted on the mast, it is fitted inside the **road cabinet** to be better protected from vandalism. To guarantee the same value of atmospheric pressure also inside the cabinet, the cabinet is provided with a pressure equalizing valve.

2.1.4 Solar radiation sensor

The determination of global solar radiation is performed through thermal difference measurements by means of a **thermopile**, which comprise high-quality thermocouples. The glass dome above it protects against cooling effects caused by wind and against soiling [4]. The sensor is designed according to the specifications included in the international ISO 9060 standard [7].

Main features can be summarized as follows:

- measuring range: 0…1400 [W/m^2];
- global radiation range: 315…2800 [nm];
- operating temperature: -40 … 80 [°C];
- response time (95%): <18 [s];
- non linearity: ± 2.5%;
- sensitivity: 5... 15 [µV/ Wm^2];
- designed in accordance to the international standard ISO 9060.

Figure 10: Solar radiation sensor,

The Pyranometer is fitted with a **radiation protection screen** (not visible from the above picture) and is mounted near the air temperature and humidity sensor at 2,5 [m] height

(Figure 2). Particular attention must be put on the fact that the vertical mast must be oriented north side in order to avoid measurement errors due to its shadow.

2.1.5 Wind direction and intensity sensors

The anemometer and the wind vane measure respectively the **speed and direction of the wind**. In particular, wind speed is measured through a **three-armed cup rotor**, fail-safe, while wind direction is measured through a dimensionally stable **blade wind vane**. Both sensors are equipped with own magnetic position encoder systems. The optimal heating of the sensor head and minimum power demand of the system are made possible by thermal decoupling of the housing shaft [5].

Figure 11: Wind direction and intensity sensors.

Main features can be summarized as follows:

- operating temperature: -30…70 [°C];
- operating wind intensity: 0.7… 60 [m/s]
- accuracy of the wind vane: ±2%;
- accuracy of the wind : ±2%.

The wind sensors are mounted on the top of the mast, one sensor at each end of the horizontal arm at approx. 5 [m] height (Figure 3).

2.1.6 Present weather sensor

This sensor detects the **type** and **intensity** of **precipitation phenomena**; it can discriminate between snowfall, rainfall, hail and mixed precipitations and classify them according to its level of intensity. From a technical point of view, the sensor is an **optical disdrometer** [1].

Main features can be summarized as follows:

Figure 12: Precipitation sensor.

- detection of any precipitation type and of the correspondent intensity level without the delays typical for other measurement instruments (e.g. rain gauges);
- high sensitivity and reliability even in extreme conditions;
- self-diagnosis functions;
- internal heating to avoid condensation or snow accumulation;

- operating temperature: -30 [°C] … 60 [°C].

The present weather sensor is mounted on top of the mast near the wind sensors at the height of about 5 [m].

2.1.7 Traffic sensor

This non-invasive sensor based on **single microwave technology** can **detect** stationary and **moving vehicles** and **classify** them into different categories with an accuracy similar to that of an induction loop device. It can also gather other essential information for traffic engineers such as vehicles category, distance (quantified in terms of gap or headway), direction, and speed.

Main features can be summarized as follows:

- classification of vehicles into 9+1 categories (Italian reference traffic classification standard);
- low-energy consumption;
- operating temperature: -20 [°C] … 60 [°C]

Figure 13: Non-invasive traffic sensor.

2.1.8 Road surface conditions sensor

This sensor has been designed to monitor the road surface conditions; it can detect the **underground** (at 4 [cm] depth) and **surface temperature** and also the **saturation level** of the liquid film on the road. This technology, which implements the **invasive and passive measurement approach (four electrode principle)** [1], represent an important instrument for planning the winter road clearance with the possibility to set alarms in case of dangerous conditions [8].

Main features can be summarized as follows:

- shielded from solicitations coming from traffic, weather, and anti-icing chemicals;
- transducer: three aluminium electrodes and two thermo resistances (class PT100), for a total of four connections;
- classification of road surface condition into 6 different categories;
- typical accuracy: ± 0.2 [°C];
- operating temperature between: -40 [°C] … 70 [°C].

Figure 14: Road surface conditions sensor.

Four sensing units are installed on the road surface in front of the cabinet in the middle of the near lane, as illustrated in Figure 4.

2.2 Road weather monitoring station final configuration

The road weather monitoring component of the first static RWIS station was finally completed during year 2013 with two **additional temperature sensors** for measuring air temperature and the **road sub-surface temperature** (RSST) at – 40 [cm]. Further ideas like the investigation of viable **cloud covers** or **lightning sensors** were not developed in the scope of the project because available technologies still need substantial research or are not directly related to the project’s objectives, respectively.

2.2.1 Additional air temperature sensor

An additional air temperature sensor has been placed near the probe described in paragraph 2.1.2. This sensor implements the same sensing technology but is characterized by the fact that it is **ventilated**. Thanks to this feature, the sensor should be more robust in terms of uncontrolled heating phenomena of the unit, which can significantly reduce the accuracy of the measurements.

Main features of the ventilation system are the following:

- operating range: -30 [°C]… 60 [°C]
- material: aluminium;
- protection class: IP54;
- ventilation features: 3.5 [m/s], 900 [l/min];
- lifetime (at 40 [°C]): about 70.000 [hours]

Figure 15: Ventilated air temperature case.

2.2.2 Road sub-surface temperature sensor

Road sub-surface temperature is measured by means of a **soil depth thermometer** consisting of a **PT100 1/3 DIN probe** encapsulated in a metallic housing.

Main features can be summarized as follows:

- accuracy ± 0,2 [°C];
- robust IP68 stainless steel housing;
- measuring range : -40 [°C] … +50 [°C]

Two probes are installed in correspondence of this RWIS station installation. One probe is installed exactly **under the road surface**, and the second one is installed **beside the road**.

The reason for this choice was to empirically assess possible variations in the sub-surface temperature measurements due to the different nature of the upper terrain layers. In case such variations demonstrate to be sufficiently negligible, one could in fact get the important indication to install such a probe near the road, with evident benefits in terms of installation needs.

Both probes are installed at a **depth of 40 [cm]** under the surface. This choice was not casual, but directly linked to the need to properly feed road weather models under investigation in the project, in particular METRo [1].

Figure 16: Road sub-surface conditions sensor.

2.2.3 Final design scheme vs local implementation adaptations

From a design perspective, this station follows the final static RWIS station design, presented in deliverable D.B1.1 [3]. This implementation is however different in a few points, that are here summarized:

- this station has more analogue inputs because of the additional air temperature and relative humidity sensor probe;
- the barometric pressure sensor is connected to a differential input.
- the mVolt input in this outstation is not very reliable. Thus the solar radiation sensor is connected using a 0..5 [V] input and an external amplifier;
- generally speaking, the connection scheme and the connector block use is slightly different from the designed one.

2.3 Air quality monitoring station

The equipment used to measure **PM10 concentration** on ambient air is a **gravimetric measurement equipment**. According to the reference national law D.Lgs 155/2010 [8] and the reference European norms UNI EN 12341:1999 [9] (now updated by norm UNI EN 12341:2014 [10]), gravimetric analysis represents the official method for the measurement of the concentration of this air pollutant.

The measurement process is the one presented in Figure 17.

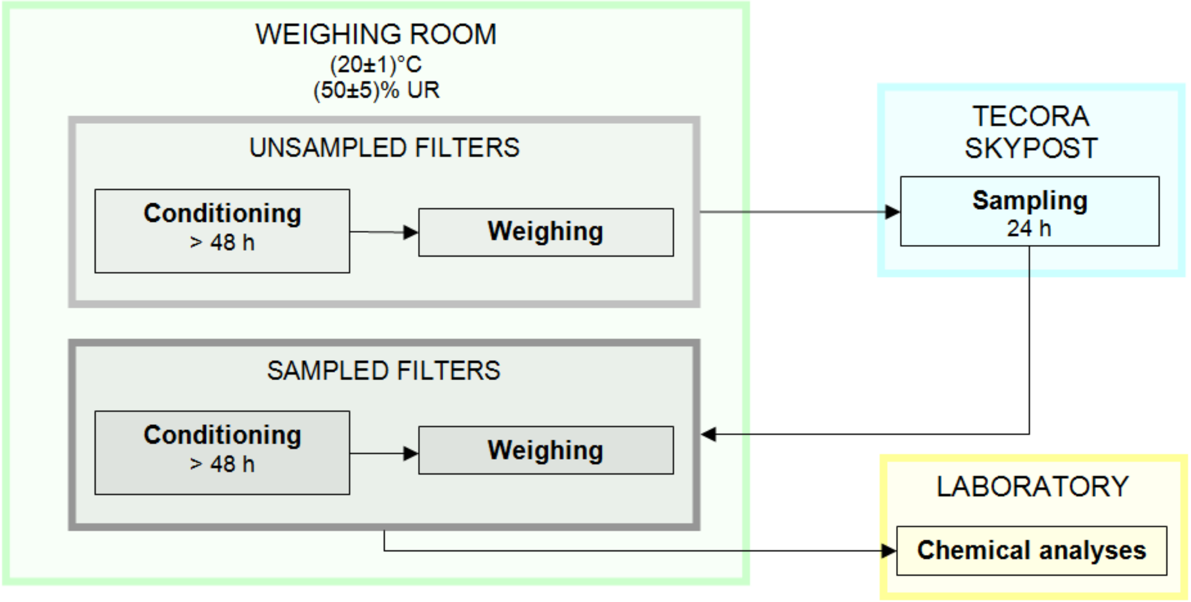

Figure 17: Air quality monitoring station measurement process.

Ambient air is passed through a size-selective inlet at a known, constant flow rate. The relevant PM fraction is collected on a filter for a known period of nominally 24 hours. **Teflon membranes** or **quartz filters** have been chosen for this purpose. The mass of the PM material is determined by weighing the filter at pre-specified, constant conditions before and after collection of the particulate matter. A climate-controlled facility is used for conditioning and weighing the filters (Figure 18). The balance used is installed and operated within the weighing room and has a resolution of 0.10 [μg].

Prior and after sampling, all filters are uniquely identified, conditioned in the weighing room at (20±1)°C and (50±5)% relative humidity for more than 48 h, and then weighed.

In order to collect PM10 on filters, an automatic outdoor station for continuous atmospheric particulate monitoring is used. The selected instrument is **Tecora Skypost PM HV** (Figure 18). It can store up to 16 filtering membranes, and thanks to its automatic sequential substitution of the filtering membrane and its electronic flow rate controller it possible to have continuous, unattended operations as well as an easy replacement of the exposed filters without interrupting the sampling [11]. The sampling inlet ensures a flow rate of 2.3 [m^3/h], in line with the aforementioned EN norms.

Main technical specifications can be summarized as follows:

- measured air pollutants: **total particulate matter**, **PM10**, **PM2.5** and **PM1, heavy metals**;
- **additional atmospheric measurements**: atmospheric pressure, pressure drop on filter, ambient temperature, dry gas meter temperature;

- volumetric measurement with dry gas meter within ±2% precision;
- **sampling probe ventilation system**, to guarantee a differential temperature between the filter and the sample inlet of maximum 5 [°C];
- GSM modem for remote control and RS-232 for on-site connection needs.

Finally, sampled filters, conditioned and filters, are analysed chemically in laboratory. **Source apportionment techniques** are then applied on the base of these measurements, as better illustrated in the output deliverables of Action C2 [12] - [13].

Figure 18: Air quality monitoring station – climate-controlled facility (left) and particulate monitoring instrument (right).

2.4 Water quality monitoring station

The water quality monitoring station is more specifically a measurement system for collecting run-off waters, which can then be characterized from a qualitative and quantitative point of view. Differently from air quality monitoring, no standardized methodologies exist in this domain. For this reason, the most promising activities observed in the literature have been considered and adapted for the local needs.

The measurement system is characterized by different components:

- a **rain gauge** for in-situ **measurements of natural rainfall**;
- a **water level probe** for measuring **runoff flow rate**;
- an automatic sampler for sample collection;

- various **on-line sensors** for **in-situ monitoring of water quality**;

- electronic instrumentation to record and transmit data via cellular connection.

Local rainfall data acquired as close as possible the monitoring station are important to give a more complete description of meteorological conditions in a monitoring period. For such monitoring requirements, the present weather sensor of the road weather station is not sufficient because quantitative measurements of the fallen precipitation are needed. For this reason, a traditional **tipping bucket rain gauge** has been chosen. The gauge has a resolution of 0.1 [mm], i.e. after 0.1 [mm] of precipitation an electrical signal starts to be recorded, and gives back the cumulative rainfall (expressed in [mm]) or rainfall intensity (expressed in [mm/min] or [mm/h]). It is important to underline that the rain gauge allows only liquid precipitation to be measured. To distinguish between rainfall or snowfall events, the rain gauge data must be compared with the precipitation type measurements of the present weather sensor.

Figure 19: Water quality monitoring station – rain gauge.

The rain gauge used is a **Isco 674 Rain Gauge**, whose main technical specifications can be summarized as follows [14]:

- sensitivity: 0.1 [mm];

- accuracy: ± 1.5% at 5 [cm/hour]; +3.5% / - 9% up to 13 [cm/hour];

- capacity: 38 [cm/hour];

- operating temperature: 0 [°C] … 60 [°C]

Accurate **flow measurement** is essential in the monitoring of runoff water and for the correct determination of the pollution loads. Continuous measurements of flow rate, at a sampling of about 1 [min] are performed in an open channel where the hydraulics is controlled using a triangular weir. The discharge through the triangular weir is directly related to the depth of the flow measured by a water level probe (a **pressure transducer**). Flow rate is then calculated using curves based on the geometry of the standard triangular weir.

Temperature, **turbidity** (a surrogate parameter of suspended solids) and **conductivity** are measured in-situ using on-line sensors at a sampling rate of 1 [min]. Two instruments are used in order to avoid occasional loss of data:

- **SC 200 instrument** equipped with a **3798-S sc conductivity sensor**, provided by **Hach-Lange** [15] - [16];
- **DL/N70** instrument provided by **STS Italia**.

The **Hach-Lange** sensor is a **digital inductive conductivity sensor** which is able to perform **temperature** measurements through a **PT100** sensing unit. Conductivity inductive measurements are particularly suitable in case of polluted surface waters and therefore preferred for this application. Main technical specifications can be summarized as follows:

- temperature measuring range: -5 [°C] … 60 [°C]
- temperature T90 response time: 2 [min]
- conductivity measuring range: 250 [µS/cm] … 2.5 [S/cm]
- conductivity T90 response time: < 15 [s]
- maximum flow velocity at the sensor: 4 [m/s]

Figure 20: Water quality monitoring station – Hach Lange conductivity sensor.

The same measurements can be obtained through the **DL/N70 STS Italia** instrument. In this case, the specifications are the following:

- temperature measuring range: -5 [°C] … 50 [°C]
- temperature resolution: 0.1 [°C]
- temperature accuracy: ± 0.25 [°C]
- conductivity measuring range: 20 [µS/cm] … 20 [mS/cm]
- conductivity resolution: 1 [µS/cm]
- conductivity accuracy: ± 2%

Figure 21: Water quality monitoring station – STS Italia conductivity sensor.

An **automated sampler** was finally installed in a closed adjacent structure of the monitoring station for collecting a series of samples to be individually or composited analysed. The water is sampled according to aliquots of 0.25 – 1 [L]. The sampling process is automatically triggered when (i) water level reaches a certain depth (condition directly associated to the beginning of precipitation event); or (ii) certain values of water peculiarities such as conductivity or turbidity are detected by means of the on-line sensors. For a proper resolution in time, sampling intervals were selected to be 15 [minutes] long, extended to 30 [minutes] in periods of slow melting of snow.

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