LIFE+11 ENV/IT/002

CLEAN-ROADS

Action A2: Project Requirements Analysis

D.A2.1

Target users functional requirements

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1. Introduction

The main objective of Action A2 is to identify and weight the different categories of requirements that need to be taken in consideration in the process of design, implementation and integration of the proposed CLEAN-ROADS system (Figure 1).

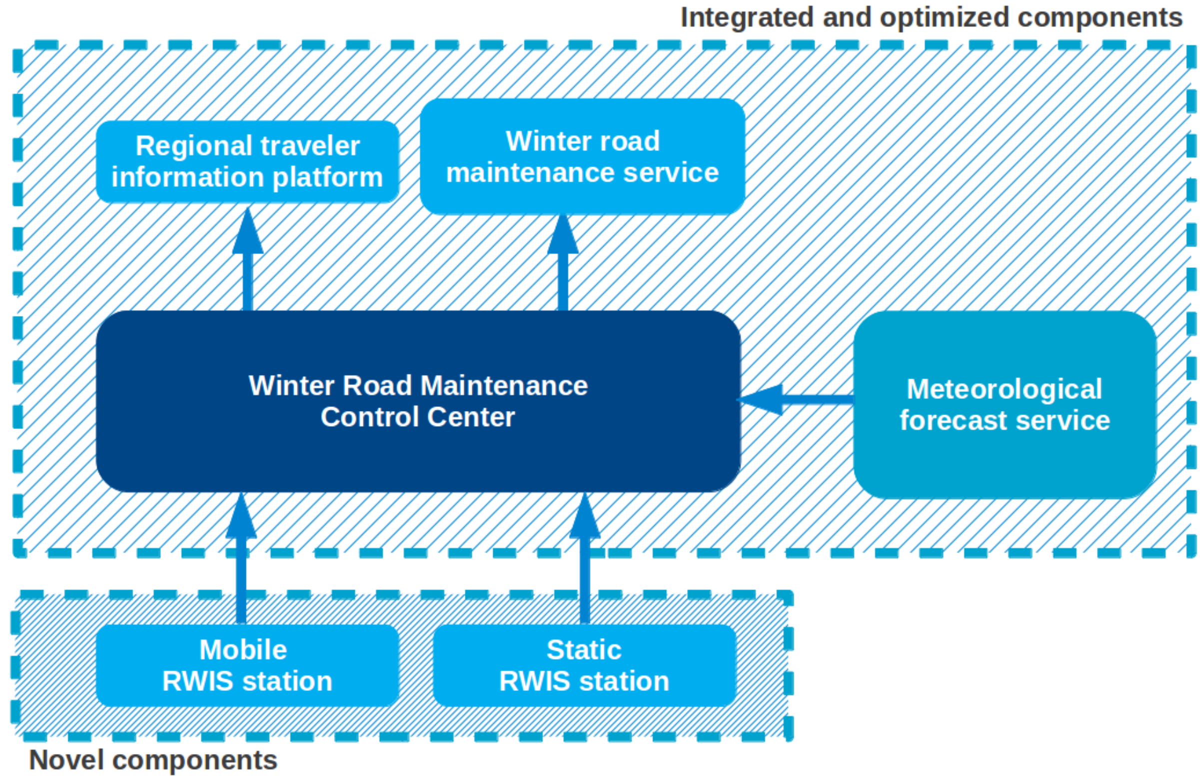

Figure 1: The high-level architecture of CLEAN-ROADS.

In particular two different requirements level will be addressed:

- **users' requirements**, that will specifically tackle functional and user acceptance aspects by considering the effective needs and perspectives of the different user categories;
- **technological requirements**, that will analyze the variety of technical constraints that need to be taken in consideration in order to properly design the system and its different components.

This report summarizes the activities and results carried out within Task A2.1, which is responsible of the users' requirements studies. It is highly recommended to evaluate the contents presented in this document jointly with deliverable D.A2.2 "Technological instruments and constraints", which is the output of the technological requirements evaluations carried out in Task 2.2 [1].

Three main users' categories are specifically taken in consideration in this requirements analysis process, namely:

* the **Road Management Service of the Autonomous Province of Trento**, which has the responsibility of defining and actuating ordinary and extraordinary plans that are needed in order to properly guarantee local high road safety levels during the winter period safe;
* the **road operators**, who are in charge of performing the winter road maintenance activities based on the received treatments instructions;
* the **travelers**, who move on an daily/seasonal basis on the local roads and therefore necessitate of safe and efficient road conditions for their trips.

The deliverable of the action A2 are the ground layer for the following activities of the project, since most of the decisions regarding the planning, the implementation, the testing and the validation of the CLEAN-ROADS system will be made on the basis of the technical and non-technical evaluations defined at this level.

From a methodological point of view, the project follows the **V-model approach** (Figure 2), which is a common structure for engineering processes, especially in the field of ITS pilot project [2].

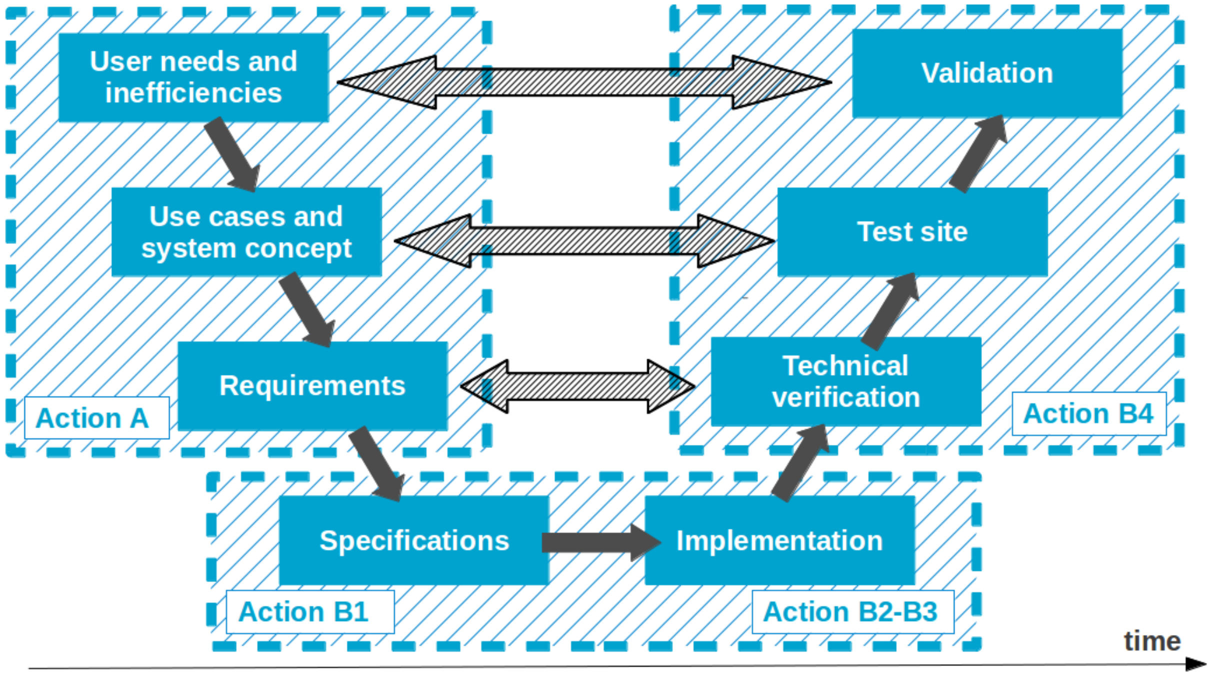

Figure 2: The V-model approach adopted within CLEAN-ROADS.

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 analyzing if the system is in the condition to efficiently match the needs of the final users.

1.1 Requirements definition process

The definition of the requirements has followed the process illustrated in Figure 3.

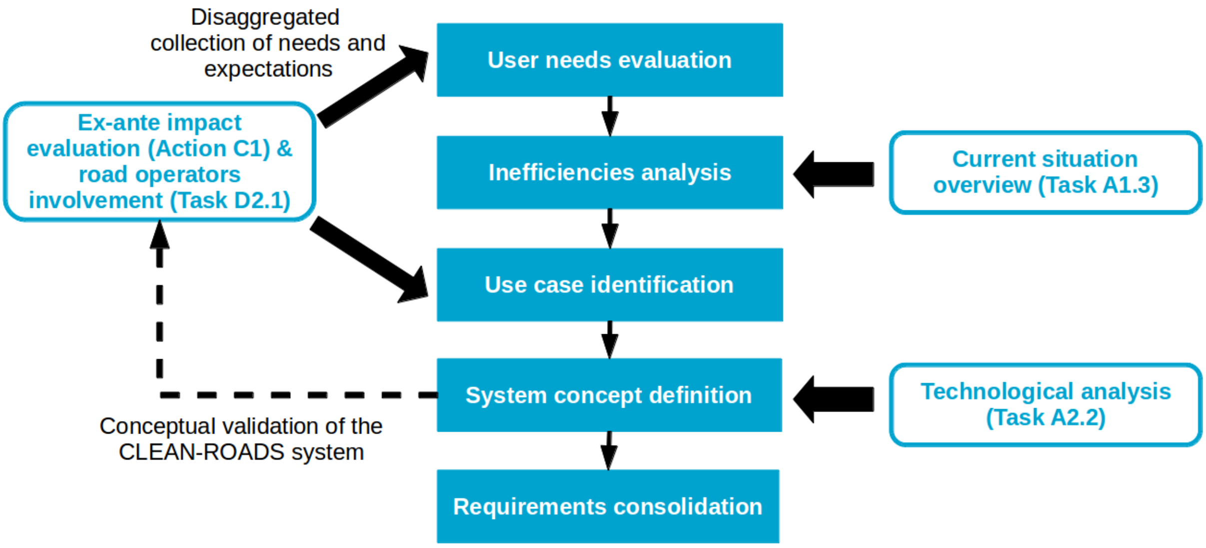

Figure 3: The reference requirements definition process adopted within Task A2.1.

User needs have been first evaluated, where possible, through a direct relationship with the target audience. This activity was particularly carried out together with the road operators and the Road Management Service of the Province of Trento, in partnership with Task D2.1. As far as local travelers is concerned, reference studies available in the local and national literature have been taken into account, and reference needs (and actual / future use cases) where directly assessed through the public survey organized within the ex-ante impact evaluation of Action C1. User needs have been then compared with **observed inefficiencies**, which were realized on top of the data collection campaign results obtained in Task A1.3. **Future use cases**, i.e. reference scenarios to be deployed on top of CLEAN-ROADS, were then proposed and discussed with the reference target audience through the opened channels, and the **system concept** was defined according to the technological assessment of Task A2.2. Finally, a list of reference **high-level requirements** was consolidated, in order to provide an operative and consolidated input for the design and implementation actions (Action Bundle B).

1.2 Deliverable structure

The deliverable is structured according to the proposed requirements definition process. Chapter 2 presents the identified users' needs, whereas in Chapter 3 the local inefficiencies are evidenced based on the empirical observations based on a proper correlation activity of different available traffic / meteorological / accidents / treatments data. Chapter 4 provides an overview of actual and future use case, and the overall system concept is described in Chapter 5. The final list of requirements is finally available in Chapter 6.

2. User needs

The objective of this chapter is to identify and analyze the specific needs of each user category which is in relationship with the project target. These needs have to reveal in a non-consistent form and based on their specific perspective both critical aspects which are actually present in this application domain as well as their different expectations towards the system. Needs include both **explicit statements** (i.e. considerations which have been clearly stated) and **implicit desires** (i.e. expectations which are not clearly stated but are intrinsically latent).

Before entering into the details of the results of the user needs analysis it is important to provide a **definition of "user"** which applies for the CLEAN-ROADS project:

an "user" is considered "an actor that is directly interacting with the CLEAN-ROADS system, in particular through a specific interface and/or on the base of a specific application".

If we take in consideration this definition, it is possible to identify three different kind of users:

- **road maintenance manager**: is an employee of the Road Management Service of the Province of Trento who has some kind of responsibility towards the winter road maintenance activities, and is specifically in charge to define and control the way they actually take place;
- **road operators**: are workmen within the staff of the Road Management Service of the Province of Trento who are in charge to carry out the winter road maintenance activities. Two different profiles may be identified, namely:
    - **a crew chief**, who is responsible of the activities carried out the team he is leading and of the specific treatments to be applied on the roads under his competence;
    - **one or more crew members**, who follow the instructions of their chief and operatively apply the treatments on the roads;
- **traveler**: this category mainly includes all motorized vehicle drivers that uses a motorized vehicle to make a trip on the road network of the Autonomous Province of Trento. More generally, it can be extended to all regional population, even to those travelers who prefer public transportation or other transport modes (foot, bicycle), since their travel choices could be theoretically influenced by the road weather information and alerts provided by the CLEAN-ROADS system.

2.1 Road maintainers' needs

The overall perspective of the road maintenance service is based on two simple ma crucial conflicting needs, namely:

- **the need to guarantee during every meteorological condition safe and clean roads as well as efficient trips from all possible origins to all possible destination**. This requirement is mainly focused on all motorized vehicle drivers that uses a motorized vehicle to make a trip on the road network of the Autonomous Province of Trento, but more generally, it can be extended to all regional population, even to those travelers who prefer public transportation or other transport modes (foot, bicycle), since their travel choices could be theoretically influenced by the road weather information and alerts provided by the CLEAN-ROADS system;
- **the** (mainly economical) **requirement of minimizing resources and costs** which are needed for carrying out the winter road maintenance operations that are necessary for guaranteeing the above "ideal" level of services.

For this reason, it is important to create, manage and monitor an internal organizational structure which is able to properly define the treatments that need to be applied to roads based on the current meteorological conditions and to quickly put them in practice. In this sense, a proactive approach is fundamental, since it can significantly reduce, giving the same target road safety levels, the amount of salt which is needed to prevent the formation of ice on the road surfaces. Reactive treatments require typically more time, chemicals and equipment, and therefore have a higher impact on operational costs and on the environment, even if in some cases they are necessary in order to not throw away the available chemicals (e.g. in occasion of heavy wind and / or rain forecasts, which are likely to wash away the chemicals that was laid before any possible ice formation event).

The user needs of road maintenance managers were assessed during several meetings organized during the first stage of the project and are summarized in Table 1.

ID	Title	Description
RM_1	**Decision Support System scope**	Road operators are actually the main responsible of their treatment actions and decisions, and are often asked to justify their operations, especially in case of some road accident involving local drivers. It would be very important to introduce a system which can actually provide just a support for those actions and decisions, but does not substitute them in this crucial decision-making process
RM_2	**Salt scarcity**	It is more and more difficult to have at disposal big amounts of **sea salt** for winter road maintenance operations. The common alternative is to use **salt produced within mines**, which is unfortunately much more pollutant. Having a smart decision support system at the base of the decision-making process can reduce wastes of chemicals.
RM_3	**Optimization margins**	Based on previous empirical pilot experiences, the highest level of efficiency are probably to be found at lower altitudes, where the probability of making a road treatment during the winter season is lower and a decision support system can really make the difference. The main added value would probably be **not specifically to improve the treatments which are probably necessary, but** more **to identify pattern situations where treatment actions can be probably avoided** without any (significant) impact on road safety. This could also lead to the most relevant benefits in economic terms,

		since the greatest cost item of a treatment operations is related to the use of maintenance vehicles.
RM_4	**Road safety levels**	The **actual road safety levels** must be in any case guaranteed. The decisions support system should be able to increase the overall efficiency and reduce the environmental impact of salting operations.
RM_5	**Data & information availability**	Historical, real-time and forecast road conditions data and information are all important for improving the service; the knowledge of friction coefficient is of less importance since the road should be ideally "black" and with friction coefficient equal to one in all possible meteorological conditions.
RM_6	**Exploitation**	A decision support system must demonstrate to be easily exploitable, i.e. with the possibility to introduce the use of this instrument in other local road networks and hopefully with a coverage to be extended to the whole Autonomous Province of Trento. **Replicatability criteria** must be therefore analyzed and assessed within the project.
RM_7	**Economical sustainability**	A decision support system must demonstrate to be economically sustainable, and the **cost / benefit ratio** related to its long-term introduction has to be clearly evidenced.
RM_8	**Integration with traffic management and control**	Road maintenance operations must be carried out by taking in much more precise consideration the existing **correlations with the traffic conditions and levels**, in order also to have a much specific assessment of the road safety risks and issues.
RM_8	**Spatial dimension**	The decision support system must be able to provide **distributed road conditions information**, so that it is possible to identify particular areas associated to specific local micro-climates where a treatment is necessary (and hopefully where it is not).
RM_9	**Traveler information**	There should also be the possibility to publish selected **real-time traveler information** to the road users through the available traveler information channels. In this way, they can be more aware of the current issues on the road network and could be more and more educated about the importance of being informed while planning a trip and during its execution.
RM_10	**Traffic efficiency**	Efficient traffic conditions must be guaranteed during the winter season as well in order to maximize the **private and commercial activities** of the local population as well as the **accessibility of tourist destination areas** (e.g. ski resorts).

Table 1: Road maintenance managers' user needs .

Being the road maintenance managers directly involved in the project, these user needs can be in some cases interpreted as pre-requirements or general indications not only for the CLEAN-ROADS system but also for the CLEAN-ROADS project itself. Actually, some of them, e.g. RM_3, was actually highlighted already during the preparation of the CLEAN-ROADS proposal, and has been very important for the creation of the structure of the project actions.

2.2 Road operators' needs

The perspective of road operators is also crucial for the project, since this staff will be the main end user of the innovations introduced in CLEAN-ROADS. Understanding in great detail the current issues and expectations of this user category can thus bring to optimal design choices and put the premises for broad and high acceptance rates of the novel RWIS. The collection of users' needs were mainly done through the involvement activities organized within Task D2.1. Apart of a dialectic phase carried out through several group and/or face-to-face meetings, this joint assessment was mainly finalized through two different "plenary" meetings in presence of most of the road operators' staff responsible of maintenance activities of the CLEAN-ROADS test route, namely:

- **a first plenary meeting**, organized on 11/03/2013, which has been the occasion to present in deep the actions and objectives of CLEAN-ROADS and to start a joint discussion on different aspects of their daily work which should be improved and hopefully addressed by the project (Figure 4);

Figure 4: First plenary meeting with road operators' staff at the road inspector's house in Lavis.

- **a second plenary meeting**, organized on 05/12/2013 with the purpose to get a final validation of the user needs and expectations of the road operators' staff involved in the project (Figure 5).

A very important role in this user needs' assessment process has been played by the **crew chief** of this road operators' team, who has immediately had a very good perception about the project's goals and has been actively and directly involved within the project activities. The most relevant added value has been threefold, namely:

- the crew members were positively influenced by the perception of their chief towards the project, and this has led to a very constructive cooperation with all team members;

- the chief has pointed out several additional constraints and limitations based on his long field experience and highlighted further issues concerning the road maintenance activities of the members of his team, which without his direct commitment would have been quite hard to identify;

Figure 5: Second plenary meeting with road operators' staff at the premises of the Weather Service of the Autonomous Province of Trento.

- being in contact with other road maintenance chiefs and teams, he has having a large positive influence on the perspective that the road operators' staff as a whole is creating towards CLEAN-ROADS, and in some way is paving the way for a future, local large-scale acceptance of the RWIS which will be tested at a smaller scale within the project.

The user needs of road operators are briefly presented in Table 2.

ID	Title	Description
RO_1	**Responsibility**	Responsibility is the major issue for road operators. In case of litigations with drivers (e.g. a road accident happened as a consequence of unideal road conditions), they have to justify what they did and above all why they made certain decisions. Having a decision support system could be beneficial in that perspective, since they can have something **objective** that they can demonstrate for justifying their decisions.
RO_2	**Individual treatments**	Despite treatments are mainly defined by the chief and communicated to the members of the team, there is actually no control about the effectiveness of these established road operations. In fact, there is **only one operator per maintenance vehicle**, and no tracking / recording system on board to take trace of their effective work. On-board assistance systems, connected with both a remote center and the salting instruments (even in direction of automated treatments), would be highly welcomed also as a function of the statements highlighted in RO_1.
RO_3	**Data and information**	At present, treatments are mainly defined on the basis of (i) a

	at the basis of decision-making process	continuous consultation of the present and forecasted meteorological conditions on the “general-purpose” weather information channels, (ii) the large experience in the field and the (iii) detailed knowledge of the road stretch under their responsibility, which includes an assessment of the current conditions as well which are influenced by their treatments. This process could be significantly improved if much **more road weather raw data and elaborated / forecasted information** would be available.
RO_4	**Working conditions**	The work of road operators is not easy and often is very energy demanding. It is particularly hard and stressful during night times, when in turn one of the operators is in charge to monitor the meteorological conditions and to eventually alert his colleagues in case of need (e.g. in case a snowfall is approaching). These monitoring activities would be significantly simplified if an **automatic alert system** would be available.
RO_5	**Drivers’ education**	The local drivers and travelers have typically very high demand towards the road maintenance service, and should be more aware that driving during the winter season is completely different than driving other periods of the year. An effective innovation process in the winter mobility and traffic management must address not only the road maintenance service, but also the psychology and the perspective of the (local) drivers and travelers, through e.g. awareness-raising initiatives and traveler information systems warning them about possible road-weather issues.
RO_6	**Road operators’ training**	Actual road operators’ competences are mainly based on the personnel experience that they have gathered on the field and the know-transfer from older colleagues. Training sessions about the proper use of de-/anti chemical are in general of upmost importance to improve the efficiency of their daily work and reduce the useless wastes (e.g. salt operations done at very low temperature, e.g. -6 [°C], which do not have any kind of effects).
RO_6	**Improved proactive treatments**	When a proactive treatment is necessary / recommended, it is crucial to decide when to apply it. If it is applied too early, traffic may throw salt outside the roadway (with relevant environmental impact on the surrounding environment), whereas it the treatment is done too late, more salting resources could be necessary because ice could already have appeared. Today, all this mainly relies on the experience of the crew chief, but all this could be significantly improved if a decision support system with reference data could be at disposal
RO_7	**Treatment type definition**	Spreading sodium chloride is not always the best choice. Through the CLEAN-ROADS system, it should be possible to directly assess the effect of using other chemicals during specific road weather conditions.
RO_8	**Improved synergies with neighboring road maintenance services**	Sharing information with other organizations which are responsible of the road maintenance of neighboring road networks outside the Province of Trento (e.g. the A22 highway, the Province of Bolzano and Verona, etc.) could be very useful, since road weather events happening outside the road network of competence could then take place locally after a certain period of time. In this way, road operators can anticipate these phenomena and properly organize and define the treatment activities.

Table 2: Road operators’ user needs.

If the user needs of the operators are compared with those of the road maintenance managers, it is possible to realize further elements of the road maintenance activities which could and should be further improved by the CLEAN-ROADS system and project, namely:

- the individual treatments operations done with the maintenance vehicles;
- the nocturnal monitoring activities;
- the proactiveness of treatments;
- the definition of the treatment type;
- the necessity to have more training (in terms of know-how creation and assessment).

It is worth noting how the need of having a specific focus towards the local travelers is a common indication provided by both target groups, which indicates the relevancy of this issue in the local target scenario. What is also particularly interesting to realize is that the joint picture provided by road maintenance managers and operators is implicitly already oriented towards a *cooperative system*, i.e. with the idea to put ideally in real-time communication road maintenance central services (also from other regions), the maintenance vehicles, the road operators and the drivers and travelers. This is a very important result not only for the design of the CLEAN-ROADS system, but also in the long-term deployment perspectives which could be possible after the conclusion of this project.

2.3 Travellers' needs

As pointed out in the previous paragraphs, it is crucial to consider in the user requirements' analysis loop also the local drivers and travelers, in order to maximize the outcome of the pilot activities and more generally of the project. This task has been much more complex, since it has not been possible to have at disposal a relatively small group of people to directly involve in this process. Moreover, the problem is further complicated by the fact that the requirements of travelers can be very different, and related to the very different reasons which induce them to move on the local roads. For example, it is worth mentioning the huge differences in terms of requirements between private car drivers and heavy truck drivers operating in the logistic sectors, or between local travelers and tourists, who may know very few the road network characteristics. A single traveler can also change his / her personal behavior: e.g. during working days, when business trips can have strong travel times requirements, and during holidays, in which the demand and even the perspective towards transport means can be completely different.

For this reason, in order to properly face all these complexities, this activity has been carried out in two different steps:

- **an ex-ante evaluation of the most suitable user needs**, based on a deep evaluation of the reference state-of-art (both at scientific level but also intended in terms of local publications, articles, users' comments on social networks, etc.);
- **an assessment of these preliminary results made through a direct relationship with local travelers**, carried in strong relationship with the ex-ante evaluation

activities organized in Action C1, where a public survey was organized with the intention of both initially quantifying a set of indicators for the evaluation of the impact of the project on the target audience, as well as getting a precise feedback about the actual perception that local travelers have towards different aspects and elements related to the mobility and traffic management during the winter season [3].

2.3.1 Initial assessment results

An initial characterization of travelers' patterns was carried out by evaluating the annual reports published by Automobile Club Italia (ACI), the main national public organization for the promotion and appreciation of the automotive sector in Italy. ACI is used to carry out on an annual basis a detailed analysis on how the perceptions and habits of Italian travelers and drivers are changing over the years, and this can provide interesting inputs for the scope and purposes of this requirements analysis process.

The main report which was considered for this goal has been the ACI publication of 2011 [4], but also the indications contained in the report 2012 were taken in consideration [5]. The most interesting results which emerged from this study can be summarized as follows:

- **the car has been losing its strong attractiveness**, and is less and less considered a "status symbol" in the today's society;
- the increase of traveling costs (in particular, petrol and other fossil fuels) has produced a **significant decrease in the daily use of the private car**, and has determined as a consequence a **change in the travel habits** towards other transportation means. The type of choice is directly related to the specific mobility needs of the different users' categories (business men, pensioners, homemakers, etc.);
- the road traffic externalities in terms of safety (i.e. number of accidents and deaths on the roads) are decreasing, but there is a clear trend, in particular among **young people**, to **break traffic laws**, in particular as far as drunk driving, the use of personal devices while driving, excessive speed and red light running is concerned. Road accidents have as main cause the excessive speeds and the distracted driving, and typically involve very young drivers (among 20-24 years); a not negligible percentage of drivers (17,5%) has revealed to never get some information about safety recommendations and standards.

The trends in modal split, which are directly recalled from this study in **Fehler! Verweisquelle konnte nicht gefunden werden.** and Figure 7, put in clear evidence that (i) there is a **general increased availability (or constriction) to multi-modality**, and (ii) there are age-groups that are more open to new mobility habits, in particular younger people. The doubt that naturally raises is the following: are travel choices made in an aware way or not? The impression is that a lot could be done in order to let travelers decide for more efficient trip options. A latent (or implicit) and general user need is therefore the possibility to have a **smart travel decision support system**, which can dynamically orientate travelers among the different travel options.

Another important indication which raises from this study is the clear identification of two opposite driver patterns:

Tab. 1.6. - Mezzo di trasporto utilizzato per gli spostamenti ricorrenti Anni 2007 – 2010 - 2011 (val.%)

	2007	2010	2011
Automobile come conducente	90,0	90,4	83,9
A piedi	36,2	35,5	42,4
Automobile come passeggero	25,7	33,3	30,5
Bus/treno/metropolitana urbani	25,4	34,3	27,4
Moto/scooter	14,9	17,9	20,0
Bicicletta	13,7	18,7	18,3
Bus/treno extraurbani	13,9	13,4	10,4

Fonte Aci – Censis Servizi, 2011
Possibili più risposte

Figure 6: Modal split trends in the last years [4].

Tab. 1.7. - Mezzo di trasporto utilizzato per gli spostamenti ricorrenti secondo l'età 2011 (val.%)

	18-29 anni	30-44 anni	45-69 anni	totale
Automobile come conducente	74,5	88,2	84,6	83,9
A piedi	38,8	36,8	47,9	42,4
Automobile come passeggero	32,5	30,0	30,2	30,5
Bus/treno/metropolitana urbani	35,7	20,8	29,0	27,4
Moto/scooter	35,7	23,0	12,1	20,0
Bicicletta	18,2	16,8	19,6	18,3
Bus/treno extraurbani	16,1	7,6	10,4	10,4

Fonte Aci - Censis Servizi, 2011
Possibili più risposte

Figure 7: Modal split situation with age groups details [4].

- **"driver by any cost"**, whose perspective is the use his/her private car in any condition and for every purpose, and does not even take in consideration the possibility to use other transportation means;
- **"occasional driver"**, who drives his/her personal car not because he/she has pleasure in doing it but only because he/she has the necessity to do this, and who presents the main availability to consider other transportation solutions for his /her mobility needs, even through multi-modal approaches;

But what are the main worries of drivers? How much do they perceive the road maintenance an effective problem with respect their private interests? Figure 8 and Figure 9 offer an interesting picture of this, in particular if we consider the data concerning the North-Eeast area of Italy in which the Trentino Alto Adige region is located.

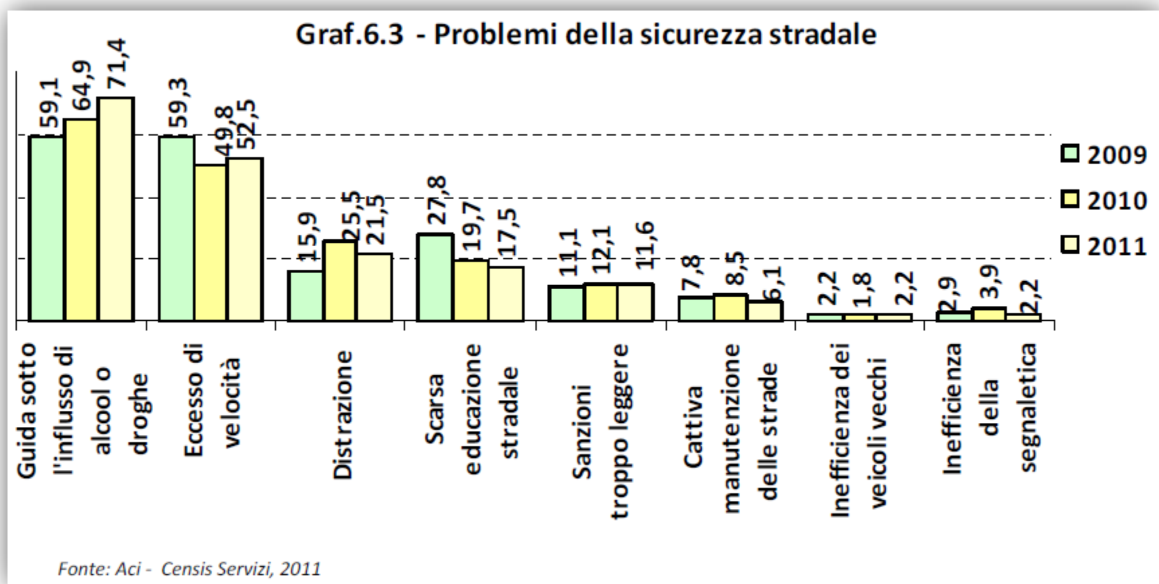

Figure 8: Road safety issues perceived by national drivers [4].

Tab.6.1. - Principale problema della sicurezza stradale per ripartizione geografica 2011 (val.%)

	Nord-Ovest	Nord-Est	Centro	Sud e isole	Totale
La guida sotto l'influsso di alcool o droghe	68,8	69,5	65,6	77,6	71,4
L'eccesso di velocità	50,5	59,7	54,3	48,9	52,5
La cattiva manutenzione delle strade	7,3	3,6	6,4	6,3	6,1
L'inefficienza dei veicoli vecchi	3,2	0,6	1,9	2,5	2,2
La scarsa educazione stradale automobilisti e motociclisti	16,6	20,5	16,4	17,7	17,5
La distrazione	23,7	19,8	24,1	19,3	21,5
Le sanzioni troppo leggere per chi causa incidenti stradali	14,4	8,4	7,7	13,5	11,6
Inefficienza della segnaletica stradale nei punti pericolosi	3,2	2,6	1,0	2,0	2,2

Fonte: Aci - Censis Servizi, 2011

Figure 9: Road safety issues perceived by national drivers – details for different Italian areas [4].

<u>Road maintenance seems to be a problem of lower importance</u> at the eyes of drivers and travelers, and the decreasing trend is probably going to be accentuated in the following years

(i.e. only 6,1% feel this, in 2010 they were 8,5% and in 2009 7,8%). This percentage is also much smaller if the only North-East area of Italy is considered (3,1%), which could be explained by better (winter) road maintenance services in these regions and/or different localized perspectives at the driver's side. In fact, in this area the highest percentage saying that one of the main safety problems is related to an insufficient road education is located (20,5%).

All these reference data has given the opportunity to create an initial reference picture not only in terms of drivers' perspective towards winter road maintenance service, but also in terms of drivers' feelings in direction of other drivers (Figure 10). The impression is that the "drivers at any cost" have very little expectations towards the road maintenance service (which could in some way explain the little aforementioned percentages), has a very efficient driving style and prepares his/her vehicle very well when the winter season is approaching. He/she has also a very bad feeling, or better a real dissatisfaction towards "occasional drivers", who have much more higher expectations towards the winter road maintenance service (probably because of their reduced driving abilities) and are typically those who may generate the biggest inefficiencies on the roads (e.g. drivers on the roads while snowing without winter gears or car chains).

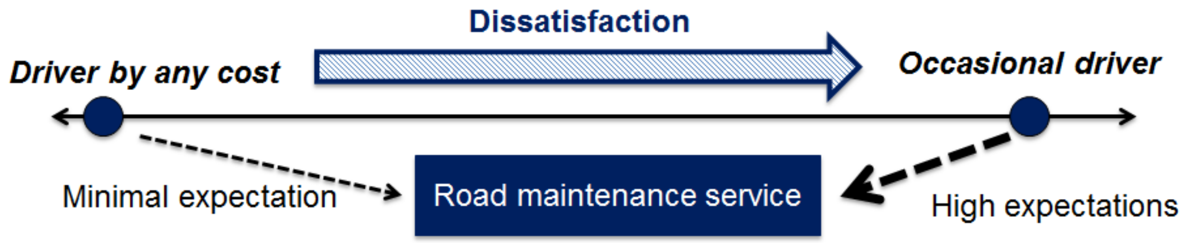

Figure 10: Drivers' opposite profiles and their relationships towards the road maintenance service.

These impressions are confirmed on one side by lots of local newspaper articles, social network comments and other user-generated information available on the local media, in which this adverse feeling towards "occasional drivers" is clearly recognizable and often widespread (e.g. Figure 11), and on the other side by the plenty of requests of compensation that drivers ask during the winter season to the regional Road Management Services, even for small accidents. Of course, in the reality we won't probably have exactly these two opposite stereotypes, but travelers which can be more or less oriented to these two reference profiles.

2.3.2 Final assessment based on public survey outcomes

In order to confirm this hypothetical scenario, and to evaluate how local travelers and drivers are balanced in it, as well as to understand more the actual perspective and needs of common people, the public survey which was organized with the primary goal to evaluate the ex-ante impact of the project on the target audience, was enriched with some specific questions aiming at investigating more on this scope [3], in particular:

RISPONDE

ALBERTO FAUSTINI

MALI D'INVERNO

La sorpresa-neve e tutti quei dilettanti

Rimango esterrefatto da sempre quando in inverno si leggono articoli che parlano della neve come una maledizione, incidenti, sale non sparso sulle strade, spalaneve inefficienti. Sembra sia colpa del comune o della provincia se la nostra auto va ad abbracciare un paracarro... Quindi mi permetto di dissentire, anche perché l'altro giorno mi son fatto un giretto, appunto perché nevicava, e ho visto delle situazioni causate da un'idiozia a dir poco imbarazzante. Gente che monta gomme stradali marcate M+S -ci sono, e di non poche marche- solo per essere a norma, senza catene a bordo, che sale -o ci prova, con scarso esito- lungo la SS350 verso Folgaria, sulla stessa strada un gruppo di ragazzetti bresciani che salgono su una grande punto con gomme totalmente estive e a bordo catene di misura diversa (mi son fermato per aiutarli, ma non ho potuto far altro che constatare l'impossibilità nel montare le catene, troppo piccole), per non parlare della maggioranza delle persone, che pur essendo correttamente equipaggiate, sono totalmente incapaci al volante. Soprattutto uomini, perché le donne la decenza di dire "non sono in grado di guidare in queste condizioni" ce l'hanno. Ad ogni modo, io mi stupisco sempre di più dell'incapacità di prendersi delle responsabilità nelle scelte che si fanno.
Siamo in Trentino-Alto Adige, non in Sicilia, e si sa, nevica spesso. Sul mercato c'è una scelta di pneumatici di tutti i generi di tutte le misure. Se si sa che il rischio di percorrere strade innevate è elevato, ci si prendano gomme ad elevate prestazioni. Costano meno di una visita in carrozzeria, soprattutto se ricostruite, le ricostruite sono buone per gli spostamenti a breve raggio, son morbide, durano meno km, ma costano pochissimo e la loro morbidezza le rende ottime su neve. Sono una scelta migliore di un treno di primaria marca usato magari per 3-4 inverni, che sono indurite e a metà battistrada. Le vie di mezzo servono solo per essere in regola, non per viaggiare sulla neve in sicurezza: Per quello servono le catene, se non sia hanno ottime invernali, che non tutte le auto possono montare. Io spero che nevichi ancora, in valle, e che iniziate a scrivere qualcosa di più sensato rispetto alle lamentele dei pretesi assi del volante che si piantano sui muri con 2 cm di neve. Perché il problema non è la condizione della strada, ma la capacità di guidare in sicurezza da parte degli automobilisti.

Davide Venturini
BOLZANO

«Tracce sulla neve»: foto scattata nei pressi del passo Campolongo, con il Sasso della Croce sullo sfondo, l'autrice è Paola Piccolruaz. Mandate i vostri scatti a lettere@altoadige.it

Guardi, sono praticamente d'accordo con lei su tutto. Ma non faccio il pilota (anche se adoro la neve e con le gomme che ho posso girare tranquillo), il gommista, l'assessore o l'esperto. Faccio il giornalista: dunque devo anche raccontare che in Trentino (e lei fa bene a scandalizzarsi) c'è ancora chi si fa sorprendere dalla piccola e breve nevicata più annunciata dalla storia. Vale per i cittadini sprovveduti (che sono tanti), vale per gli amministratori più o meno organizzati e vale per tutti. Mi scandalizzo come lei, ma non posso smettere di raccontare - anche perché raccontare serve spesso ad "educare" - ciò che accade sulle nostre strade o sulle nostre

Figure 11: A "driver by any cost" complaining about "occasional drivers" (Source: Alto Adige newspaper, 13/12/2012).

1. in case a snowfall is arriving, do you adapt your travel habits accordingly?
2. what kind of relationship do you have with your own car?
3. how do you evaluate traffic during the winter season, in terms of ice avoidance and snow removal treatments, traffic congestion phenomena, road safety and real-time traffic information availability?
4. how do you evaluate the situations in which drivers are surprised by snowfalls in winter?
5. if you could decide how to allocate public funding in this domain, where would you destine the highest resources between road maintenance or weather service improvement, real-time road weather information services, awareness-raising campaigns, professional trainings of road operators?

The respondents of the questionnaire were also given the possibility to provide free comments and suggestions concerning the topics covered by CLEAN-ROADS. This was planned with the intention to assess and include those users' needs which may not be exactly the scope of CLEAN-ROADS but that could be addressed in the next future. The results of this public survey is presented in the next pages. For more details concerning the adopted survey methodology and the surveyed population characteristic, please refer to [3].

Reaction to a snowfall

The results to question n.1 concerning the reaction to an incoming snowfall are presented in Figure 12 and Table 3.

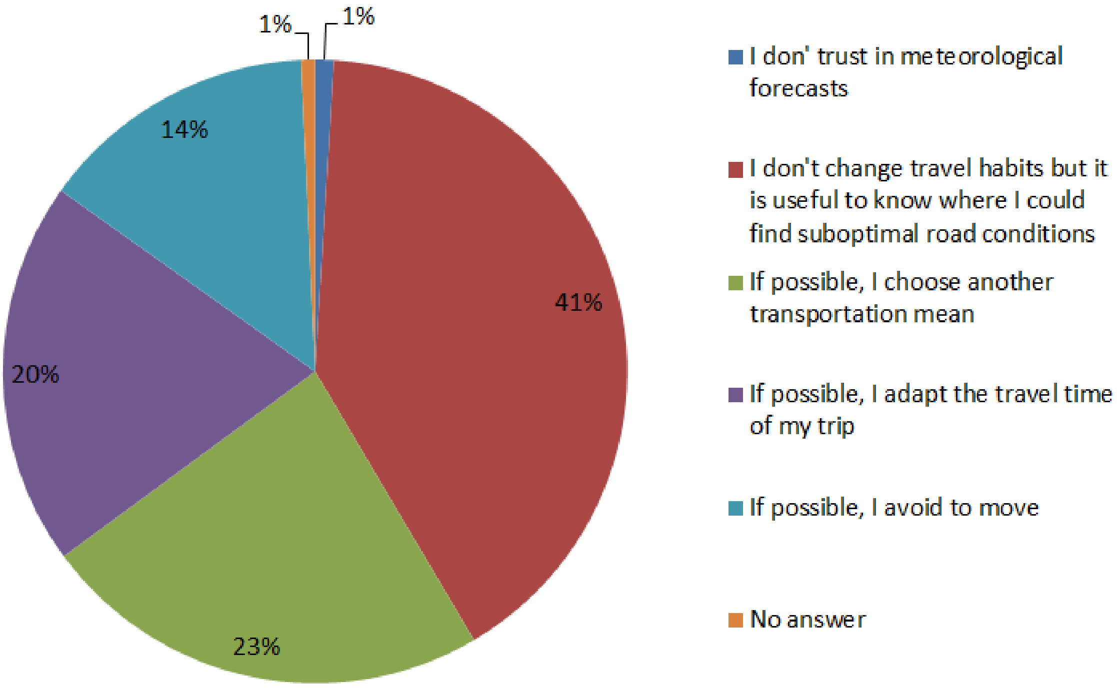

Figure 12: Public survey results – reaction to incoming snowfalls.

In case the local meteorological bulletins indicate that a snowfall is coming, how do you prepare for it?	Values (nr.)	Values (%)
I don' trust in meteorological forecasts	12	1,0%
I don't change travel habits but it is useful to know where I could find suboptimal road conditions	506	40,5%
If possible, I choose another transportation mean	292	23,4%
If possible, I adapt the travel time of my trip	249	19,9%
If possible, I avoid to move	180	14,4%
No answer	10	0,8%

Table 3: Public survey results – reaction to incoming snowfalls (details on answers).

The answers provide a first glance of the effective presence of two opposite perspectives, i.e. (i) people who are confident on their driving style and do not enter in panic even in case a weather event is coming and (ii) people who on the contrary decide to change their typical travel plans or even to avoid it. The first pattern is the most populated one, but the 57,8% revealed to take some expedient in case of similar situation. If we consider that this survey does not take into account the seasonal travelers, e.g. tourists, the impression is that the majority of the population seems therefore more oriented to the second user profile, but there is a non-negligible population of individuals which are nearer to the first user profile, and that is probably much more relevant if compared to other Italian regions, in particular the non-alpine ones.

Car ownership relationship

The results to question n.2 concerning the type of relationship that people have with their private cars are presented in Figure 13 and Table 4.

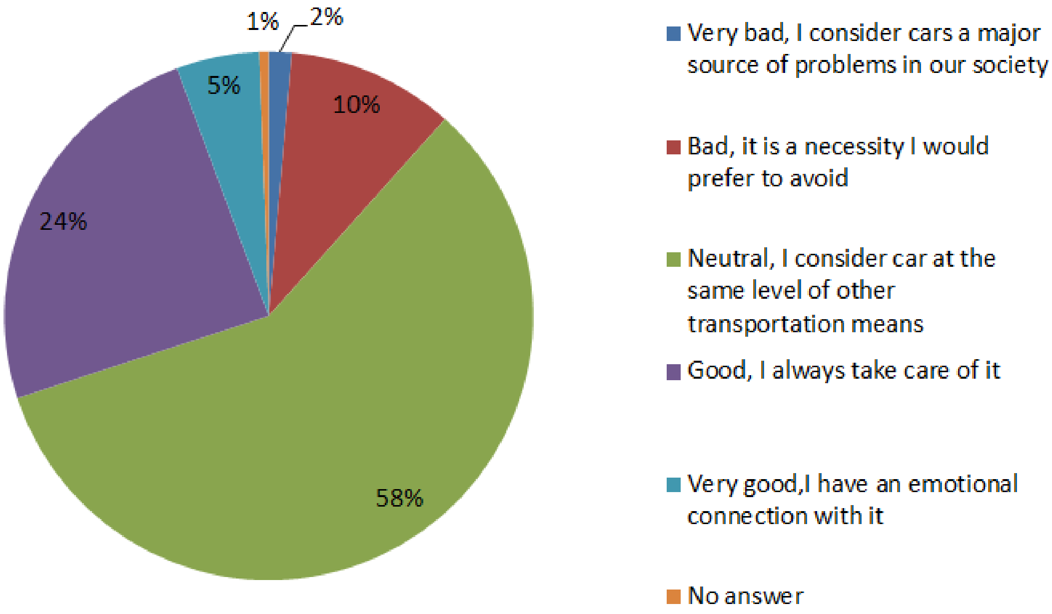

Figure 13: Public survey results – relationship with private car.

What is your relationship with your private car?	Values (nr.)	Values (%)
Very bad, I consider cars a major source of problems in our society	17	1,4%
Bad, it is a necessity I would prefer to avoid	129	10,3%
Neutral, I consider car at the same level of other transportation means	724	58,0%
Good, I always take care of it	305	24,4%
Very good, I have an emotional connection with it	67	5,4%
No answer	7	0,6%

Table 4: Public survey results – relationship with private car (details on answers).

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- the majority of travelers (58%) do not give priority to private car for their travels, and show a very high potential to consider other travel means if alternative and compatible with their dynamic needs; in some way, this is a confirmation of the on-going trends already stated in the ACI report(s) concerning an increasing openness to change travel habits, in particular in direction sustainable means;
- “driver by any costs” can be quantified in the order of 30% (i.e. people saying to have a “good” or “very good” feeling with their car), which is compatible with the above considerations about the dimension of this user group with respect the overall population.

Perception of traffic conditions in winter

The results to question n.3 concerning their perception about traffic conditions in winter are presented in Figure 14 and in the tables below.

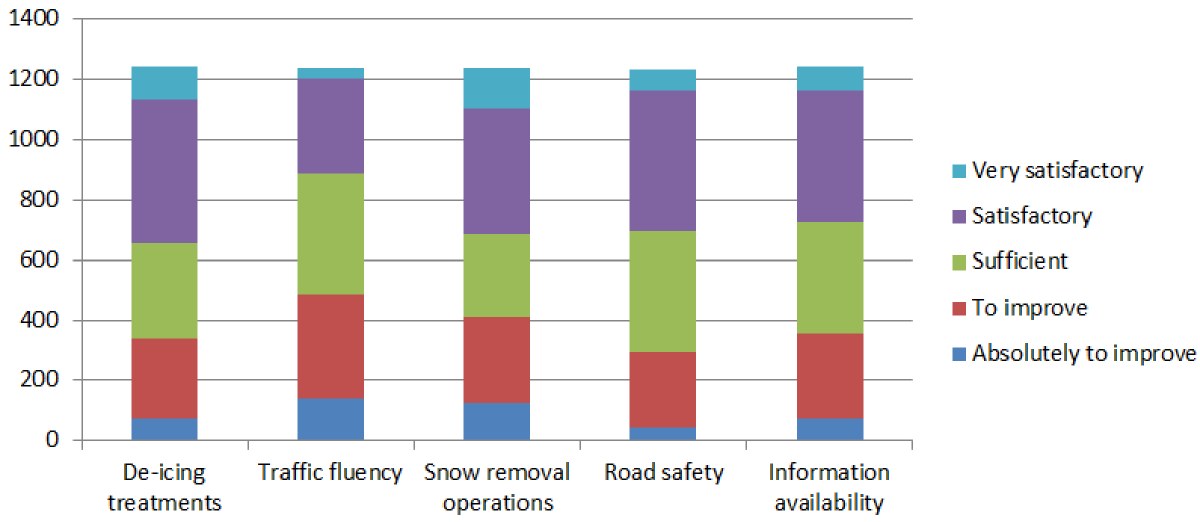

Figure 14: Public survey results – evaluation of traffic conditions in winter.

How would you currently evaluate… de-icing treatments?	Values (nr.)	Values (%)
Absolutely to improve	77	6,2%
To improve	265	21,2%
Sufficient	316	25,3%
Satisfactory	472	37,8%
Very satisfactory	111	8,9%
No answer	8	0,6%

Table 5: Public survey results – evaluation of de-icing treatments (details on answers).

How would you currently evaluate… traffic fluency in winter?	Values (nr.)	Values (%)
Absolutely to improve	139	11,1%
To improve	347	27,8%
Sufficient	400	32,0%
Satisfactory	318	25,5%
Very satisfactory	35	2,8%
No answer	10	0,8%

Table 6: Public survey results – evaluation of traffic fluency (details on answers).

How would you currently evaluate… snow removal operations?	Values (nr.)	Values (%)
Absolutely to improve	126	10,1%
To improve	284	22,7%
Sufficient	278	22,3%

Satisfactory	413	33,1%
Very satisfactory	136	10,9%
No answer	12	1,0%

Table 7: Public survey results – evaluation of snow removal operations (details on answers).

How would you currently evaluate… winter road safety?	Values (nr.)	Values (%)
Absolutely to improve	44	3,5%
To improve	252	20,2%
Sufficient	399	31,9%
Satisfactory	465	37,2%
Very satisfactory	72	5,8%
No answer	17	1,4%

Table 8: Public survey results – evaluation of road safety (details on answers).

How would you currently evaluate… information availability?	Values (nr.)	Values (%)
Absolutely to improve	73	5,8%
To improve	280	22,4%
Sufficient	374	29,9%
Satisfactory	433	34,7%
Very satisfactory	80	6,4%
No answer	9	0,7%

Table 9: Public survey results – evaluation of information availability (details on answers).

A lot of interesting information are contained in these users' indications. The most important can be summarized as follows:

- **traffic fluency** and **snow removal operations** are the aspects where most of the current dissatisfaction is localized (38,9% and 32,7% people revealed that these aspects should "absolutely improved" or "improved, respectively). It is worth noting that de-icing operations have revealed to be slightly a minor problem if compared to snow removal operations (27,4%);
- **information availability** has also revealed significant optimization margins, as stated by 28,2% of the surveyed population;
- **winter road safety** has demonstrated, as expected, to be the minor issue at all at the travelers' eyes (only 23,7%). This demonstrates the efforts of the public administration in order to guarantee a high quality of service with respect to this topic.

In any case, local travelers feel that all five winter road management topics show significant margins for improvements. Given the above considerations, the feeling is that most of the "unsatisfied" people have to be found among the "occasional drivers", whereas on the contrary most of the satisfactory comments are probably to be associated to "drivers at any cost". This in some way noticeable in the results concerning the evaluation of the snow removal operations, in which it is possible to found the minimum of answers to the item “sufficient” and two clear opposite feedbacks in terms of satisfaction. In order to further assess this, the distribution of answers of people who revealed to have a “good or “very good” relationship with their car has been specifically evaluated and compared to those who have said to have a “bad” or “very bad” feeling with it. The results of this additional evaluation can be found in Figure 15 and Figure 16, and clearly show that the majority of satisfied people are to be found among drivers “at any cost” – if this not applies in the same way for all aspects of winter road management, in particular traffic fluency and information availability[2]. The perception towards winter maintenance operations (i.e. de-icing treatments, snow removal operations and road safety) is where this discrepancy is clearly most evident.

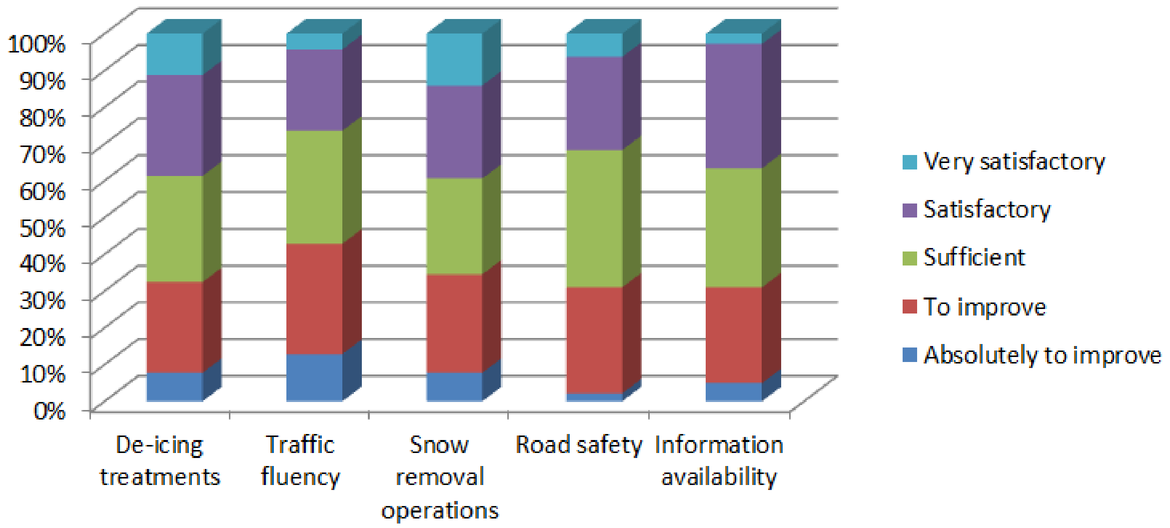

Figure 15: Public survey results – evaluation of traffic conditions in winter (“occasional drivers” perspective).

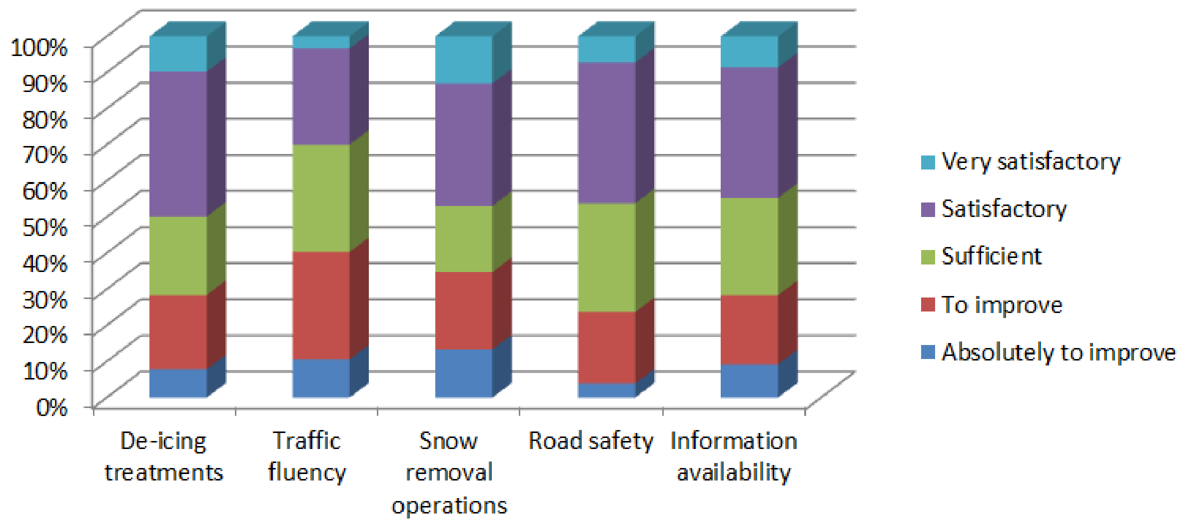

Figure 16: Public survey results – evaluation of traffic conditions in winter (“drivers at any cost” perspective).

[2] For these specific analysis only the answers to the questionnaire in Italian language have been considered.

Evaluation of drivers surprised by snowfalls

The results to question n.4 concerning how they evaluate drivers during snowfall events are presented in Figure 17 and in the tables below. People were specifically asked to evaluate the different possible factors which lead to inefficient driving situation (e.g. non properly equipped vehicles on the road network).

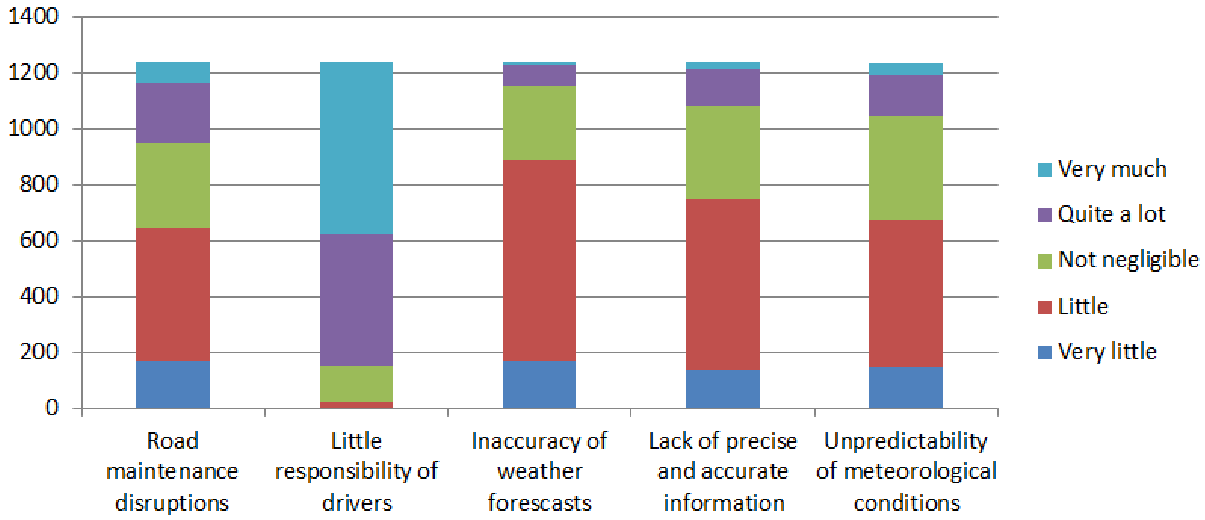

Figure 17: Public survey results – evaluation of drivers surprised by snowfalls.

What is the influence of … road maintenance disruptions?	Values (nr.)	Values (%)
Very little	171	13,7%
Little	474	38,0%
Not negligible	305	24,4%
Quite a lot	213	17,1%
Very much	78	6,2%
No answer	8	0,6%

Table 10: Public survey results – perception of road maintenance disruptions (details on answers).

What is the influence of … lack of drivers' responsibility?	Values (nr.)	Values (%)
Very little	3	0,2%
Little	19	1,5%
Not negligible	132	10,6%
Quite a lot	468	37,5%
Very much	621	49,7%
No answer	6	0,5%

Table 11: Public survey results – perception of drivers' responsibility (details on answers).

What is the influence of … inaccurate weather forecasts?	Values (nr.)	Values (%)
Very little	169	13,5%

Little	723	57,9%
Not negligible	260	20,8%
Quite a lot	76	6,1%
Very much	10	0,8%
No answer	11	0,9%

Table 12: Public survey results – perception of weather forecasts (details on answers).

What is the influence of … lack of accurate information?	Values (nr.)	Values (%)
Very little	137	11,0%
Little	613	49,1%
Not negligible	332	26,6%
Quite a lot	129	10,3%
Very much	28	2,2%
No answer	10	1,4%

Table 13: Public survey results – perception of information availability role (details on answers).

What is the influence of … unpredictable weather conditions?	Values (nr.)	Values (%)
Very little	150	12,0%
Little	524	42,0%
Not negligible	371	29,7%
Quite a lot	145	11,6%
Very much	45	3,6%
No answer	14	1,1%

Table 14: Public survey results – perception of unpredictability of weather information (details on answers).

The most relevant result here is related to the lack of drivers' responsibility, where most of the people (87,2% replied "quite a lot" or "very much") recognized that this aspect is the most important when considering this kind of common inefficiency during the winter season. As expected, disruptions in the road maintenance operations are considered as the second main inefficiency factor, and this is in line with the perspective of "occasional" drivers.

Public funding allocation

The result to question n.5 concerning the suggestions for the allocation of future public resources are finally presented in and in the tables below. While previous answers were mainly built in order to assess the overall satisfaction of local travelers, this question (together with the free comment field) aims to obtain some quantitative indication about their future expectations.

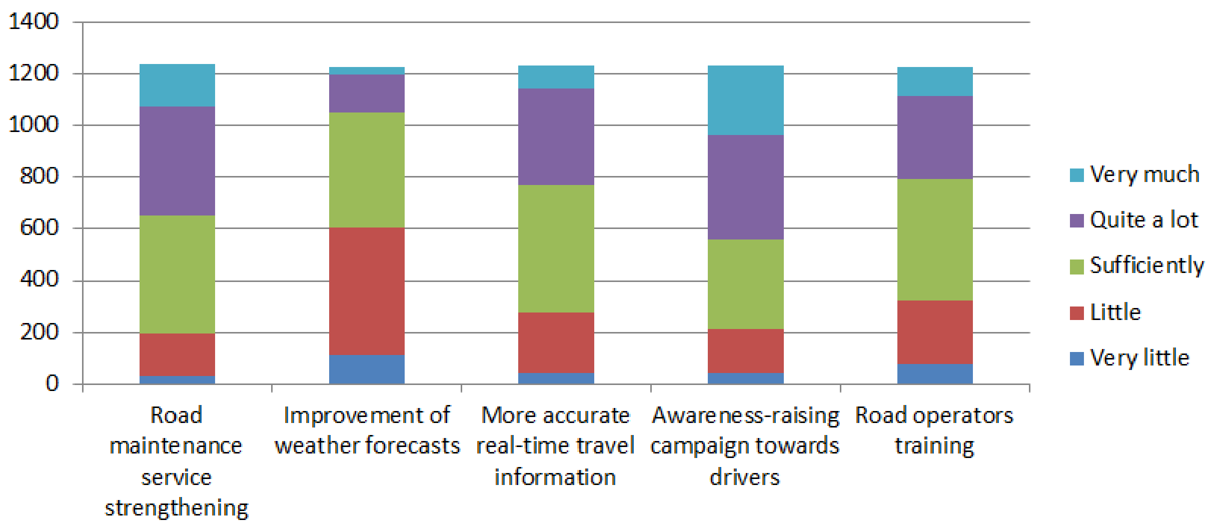

Figure 18: Public survey results – allocation of possible future public funding.

How much would you invest on… road maintenance service?	Values (nr.)	Values (%)
Very little	32	2,6%
Little	161	12,9%
Sufficiently	459	36,7%
Quite a lot	425	34,0%
Very much	164	13,1%
No answer	8	0,6%

Table 15: Public survey results – investments on road maintenance service (details on answers).

How much would you invest on… weather forecasts?	Values (nr.)	Values (%)
Very little	115	9,2%
Little	493	39,5%
Sufficiently	443	35,5%
Quite a lot	144	11,5%
Very much	32	2,6%
No answer	22	1,8%

Table 16: Public survey results – investments on weather forecasts improvement (details on answers).

How much would you invest on.. real-time travel information?	Values (nr.)	Values (%)
Very little	43	3,4%
Little	232	18,6%
Sufficiently	496	39,7%
Quite a lot	373	29,9%
Very much	91	7,3%
No answer	14	1,1%

Table 17: Public survey results – investments on real-time travel information services (details on answers).

How much would you invest on.. drivers' awareness-raising?	Values (nr.)	Values (%)
Very little	40	3,2%
Little	171	13,7%
Sufficiently	345	27,6%
Quite a lot	408	32,7%
Very much	271	21,7%
No answer	14	1,1%

Table 18: Public survey results – investments on drivers' awareness-raising campaigns (details on answers).

How much would you invest on.. road operators' training?	Values (nr.)	Values (%)
Very little	77	6,2%
Little	246	19,7%
Sufficiently	469	37,6%
Quite a lot	326	26,1%
Very much	111	8,9%
No answer	20	1,6%

Table 19: Public survey results – investments on road operators' training (details on answers).

In line with the answers provided in the previous question, the main topic that should be addressed is increasing awareness-raising initiatives towards local drivers (54,4% would invest "quite a lot" or "very much" on this), but on the other side on road maintenance service strengthening as well (47,1%) and only in part on road operators' training (35,0%). People have also expressed a certain desire to have better real-time travel information (37,2%), and very little have expressed the necessity to improve weather forecasts (14,1%).

As a conclusion of this evaluation process, a Customer Satisfaction (CS) analysis based on the indications and the results presented in [6], has been performed. The idea is to plot on the x-axis the revealed expectations of users, and on the y-axis their current satisfaction. In order to obtain this the following matches between answers to question n.4 and 5. have been created, namely: (i) road maintenance disruptions and investments for improving the service; (ii) lack of drivers' responsibility and awareness-raising campaign; (iii) reduced accuracy of weather forecasts and investments for improving them; (iv) lack of real-time travel information and investments to put them at disposal; and (v) unpredictability of weather conditions and road operators' training. For question n.4, the sum of the percentage related to the answers "very little" and "little" has been considered as the indicator of satisfaction; for question n.5, the sum of the percentage related to the answers "sufficiently", "quite a lot" and "very much" has been considered as the indicator of expectation. The results of this CS analysis are finally presented in Figure 19.

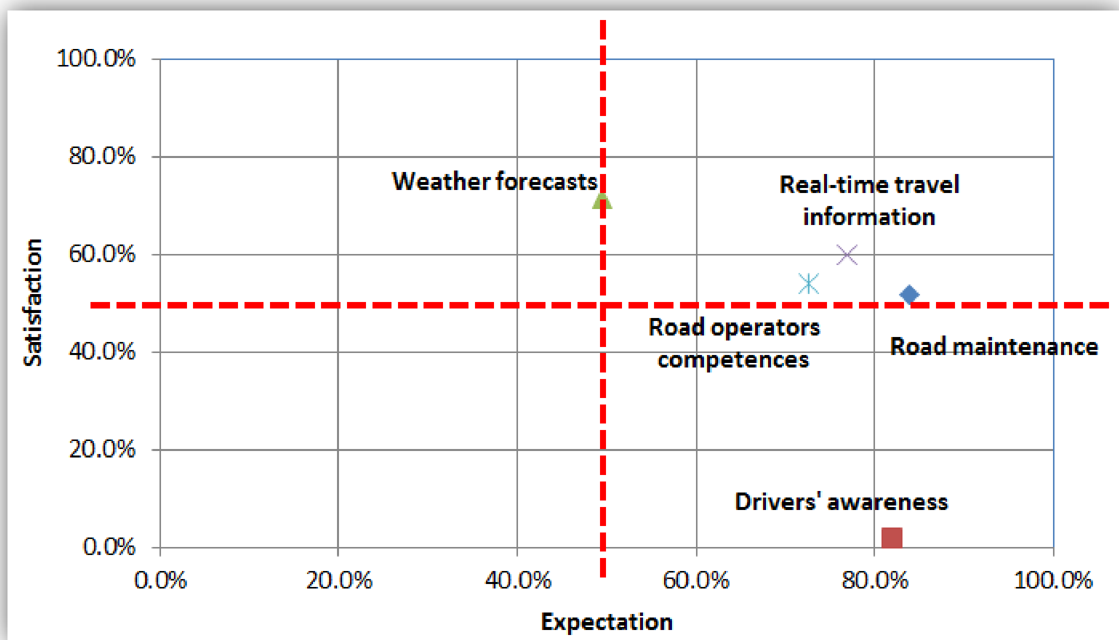

Figure 19: Public survey results – customer satisfaction analysis results.

Drivers' awareness topic is the only one that falls in the "priority improvement" quadrant (high expectation, low satisfaction), and that therefore needs to be specifically addressed not also by the CLEAN-ROADS system but also by the CLEAN-ROADS project. Road operators' competences and road maintenance service are just above the boundary line with the "maintenance" quadrant (high expectation and satisfaction), and express the need to further improve this situation. This consideration applies also on the real-time travel information topic. Weather forecasts have a significant lower expectation, since people feel that they are reliable and accurate enough for what their specific need, as demonstrated by high level of satisfaction. However, these will need to be further improved in order to match the high requirements and specifications of the road maintenance service.

2.3.3 User needs' consolidation

Based on the results of this process of analysis of the local travelers' perspective, the following set of user needs has been consolidated (Table 20).

ID	Title	Description
LT_1	**Road maintenance quality of service**	Most of the local travelers expect the highest quality of service at any time and at any location and in all possible weather conditions, all this in particular when mobility demand is highest. Most of the improvements are likely to occur when snowfalls take place; de-icing operations are considered to necessitate fewer improvements.
LT_2	**Drivers' responsibility**	Most of the inefficiencies that are observed on the local roads are likely to be created by improper actions of drivers. Actions should be carried out in order to (i) make them more aware about the impact of their travel decisions, and (ii) put them in the conditions to let them

		easily decide how to best carry out a trip, in particular in correspondence of critical weather events (e.g. snowfalls) and as far as non-local users (e.g. tourists) is concerned. Pulling and pushing actions must be carried out – “drivers at any cost” have clearly express their suggestion to introduce heavier penalties to drivers who do not respect the traffic laws.
LT_3	**Information on board**	Real-time information concerning the road conditions on board could be an added value in particular for “drivers at any cost”. This should be presented however in a way that is easily and quickly understandable form and in order to minimize the distraction.
LT_4	**Road safety levels maintenance**	Local travelers have expressed a good level of satisfaction of actual road safety levels, and desire that they are not decreased in the future.
LT_5	**Traffic fluency improvement**	Actions must be also carried out in order to reduce traffic jams during the winter season. An integrated approach with the road maintenance service is recommended.
LT_6	**Shift to other transportation means**	A lot of local travelers would change their travel habits in terms of transportation means (e.g. towards the public transportation services), but these should be improved in order to better match the travel needs of end-users.
LT_7	**Road maintenance service in the municipalities**	The project should also target the limited capabilities of the road maintenance service carried out by local municipalities, which is at present perceived to have a lower quality with respect to the regional one.
LT_8	**Road maintenance services coordination**	All public/private organizations that are responsible of the road maintenance in the Autonomous Province of Trento should improve their coordination
LT_9	**Vulnerable Road Users safety**	The project should also target not only the treatments of the motorized roads, but also of sidewalks, bicycle routes and parking areas, where many accidents involving Vulnerable Road Users take currently place.

Table 20: Local travelers’ user needs.

3. Inefficiencies

This chapter aims to present the inefficiencies that have been identified on top of the user needs presented in Chapter 2 and, were applicable, through a matching with the results of the evaluation of the field data collected during the winter season 2012/2013, which are more specifically reported in [7]. Baseline data provided by the Coordinating Beneficiary concerning the overall organization of the regional road maintenance service has also been considered in this process. The inefficiencies are organized in two different categories, depending on the main reference target groups: inefficiencies in the winter maintenance procedures and road treatments operations, and inefficiencies in the winter travel choices by local travelers.

3.1 Inefficiencies in the winter maintenance and road treatments procedures

In order to identify the inefficiencies at the road maintenance management level, it is important first to have a detailed overview on how the service is organized on the local territory. This overview is given in short in the following pages.

3.1.1 Geographical, climate and road network overview of the Province of Trento

The Province of Trento with its extension of 6.207 [km²] is one of the largest in Italy. Its territory is mostly mountainous (as appreciable from Figure 20) and its surface is mainly covered by forests (49%).

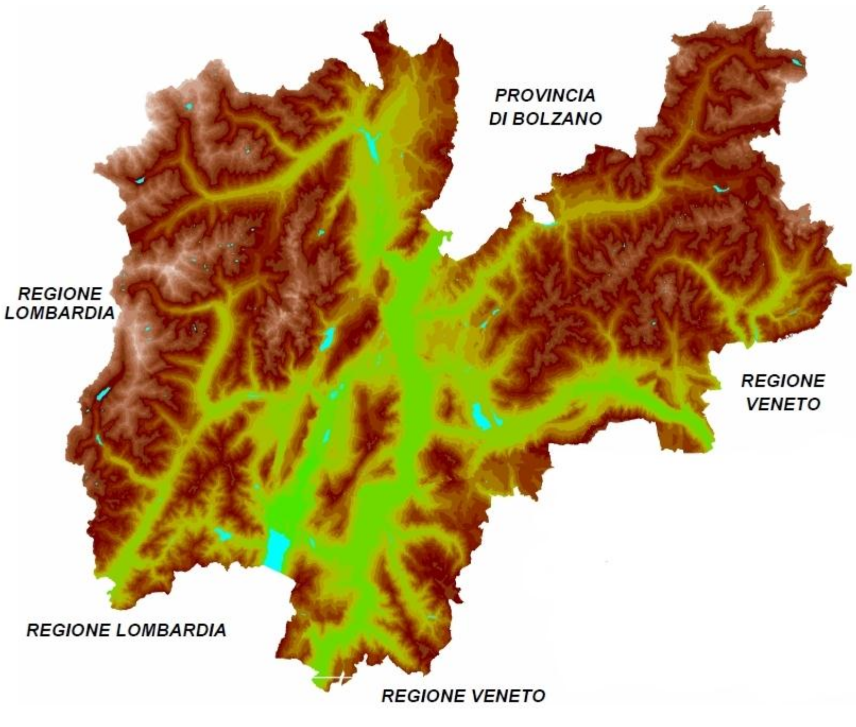

Figure 20: The orography of the Autonomous Province of Trento.

From a climatic point of view, the territory is part of the pre-alpine district, and is exposed to sub-Mediterranean influences. The annual amount of rainfall is typically higher in the south part of region (1500 [mm]) than in north (600 [mm]). Snowfalls during the winter season are typically a common phenomenon, even at the valley bottom, and their intensity is directly linked to the altitude of the different location (Table 21). Snow can remain on the ground for about 120 days at altitudes over 1300 [m] and even more (150-170 days) for altitudes higher than 1800 [m].

Altitude [m]	Snowfalls [cm]
1300	100 -180
1500	~ 200
>2000	> 400

Table 21: Typical snowfall intensities at different altitudes.

The amount of de-icing treatments depends in a strongly way on the geographic position and the climate behavior, which can present significant changes over the single winter seasons. De-icing treatments are normally carried out for in between 60 and 150 days a year.

The road network which falls under the jurisdiction of the Province of Trento extends for 2445 [km] and are divided in national roads (about 892 [km]) and local roads (about 1553 [km]). The overall altitude profile of the road network is presented in Figure 21.

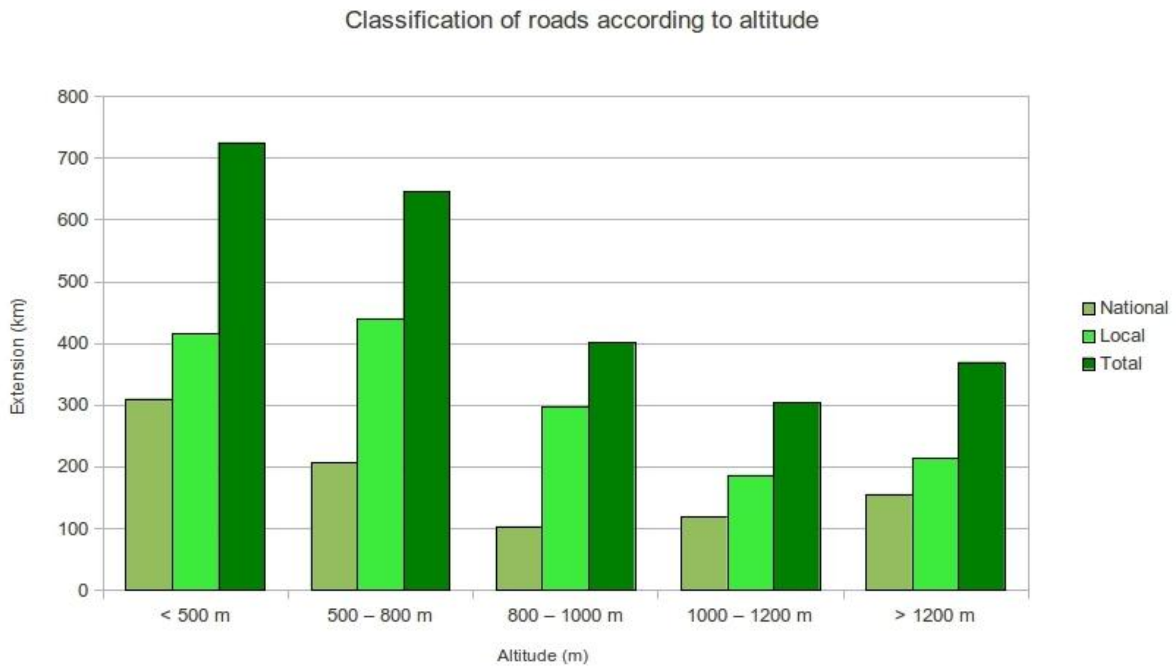

Figure 21: National and local roads correlated with their associated altitude.

Figure 22: A typical perspective of the local road infrastructure.

Local roads are of course characterized by different traffic levels. Surveys carried out in the past have allowed to distinguish and identify three main roads categories, based on their Average Daily Traffic (ADT), as reported in Table 22.

ADT [vehicles]	Road network extension [km]
< 4.000	1.825
4.000 – 10.000	375
> 4.000	245

Table 22: Road network characterized by Average Daily Traffic.

3.1.2 State-of-art in local road maintenance activities

The maintenance of the road network is done by the Road Management Service, and is organized in eight different **sectors** (Figure 23). 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.

Treatments are carried out as a function of their objective and of the meteorological conditions in which they are performed. **Sodium chloride** (NaCl - salt) 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.

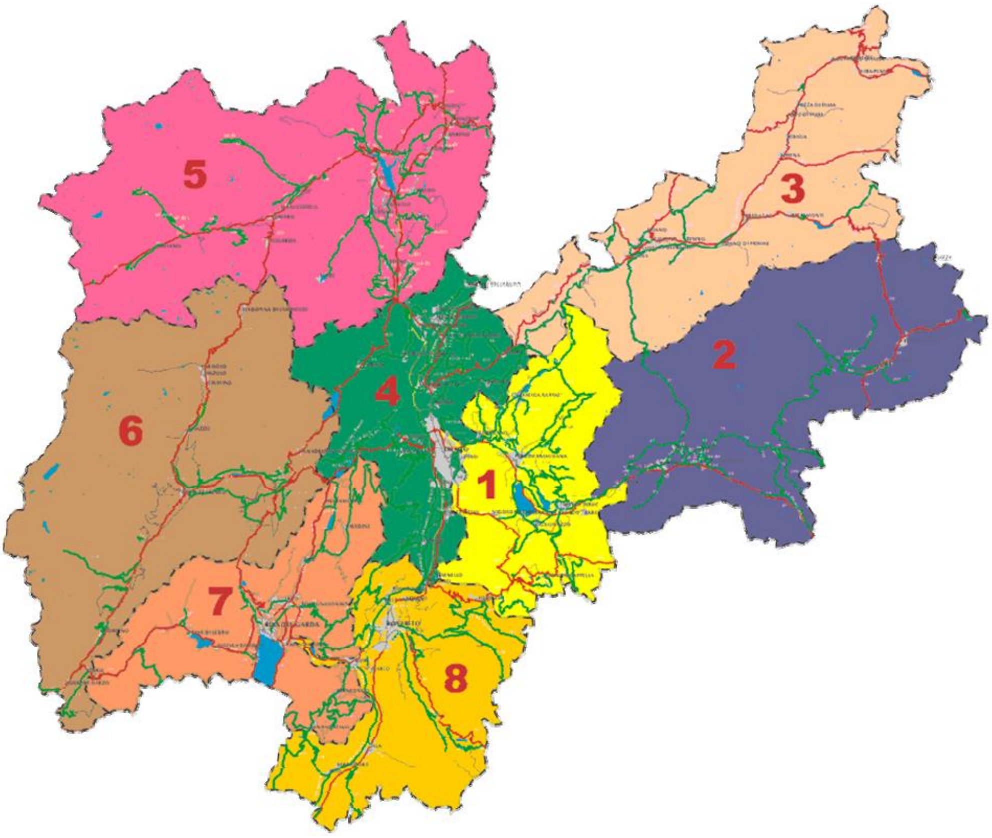

Figure 23: The eight geographical sectors which are considered in the road maintenance activities.

Salt is available in cubic crystalline form and typically in two different dimensions: 0.2 – 5 [mm] and 0,2 – 3 [mm]. It is applied after the passage of snow plough as well in order to melt the thin film of snow that may remain on the road surface. Salt-only treatments are mainly performed in the valleys at lower altitudes where the temperature are typically higher and it is therefore possible to melt snow or ice bonds with it. This kind of treatments is generally adopted on all main roads characterized by intense traffic flows and higher average speeds as well. The use of chlorides such as **calcium chloride** ($CaCl_2$) and **magnesium chloride** ($MgCl_2$) is very limited because of their negative externalities: in fact, calcium chloride is more effective because it gives faster reactions and can be applied at lower temperature as well (till -30 °[C]), but is much more dangerous from an environmental point of view and tends to create a thin layer over the road surface because of the soaping effect created by the contact with water; magnesium chloride which can moreover cause several problems to the road infrastructure.

Gravel is used to increase the friction coefficient between the road and the tires in case of ice on the surface and when temperature is too low (e.g. under -7°[C]) to melt it through salt. For this reason, the use of this de-icer, eventually mixed with conventional salt, is more likely to be located on the mountain roads or in case of lasting ice on the road surface; in general these roads have lower average speeds (not more than 70 [km/h]) and reduced traffic speeds, thus the use of gravel does not have negative implications on road safety.

Figure 24: Road maintenance vehicle in action on a local road.

Up to 20.000 tons of salt can be overall used during particularly snowy winter seasons. This quantity can be significantly reduced (even more than halved) when the number of snowfalls is significantly reduced, as it was observed in 2007 or 2012 (Table 23). As far as gravel is concerned, comparable consumptions are typically registered. As illustrated in Figure 25 and Figure 26, on average 6 tons of salt and 5 tons of gravel are spread for each kilometer of road [8]. This quantity can however change quite significantly in the different sectors of the road network as a function of their specific climatology, addressed level of service and other road peculiarities, which justify this type of decentralized control of the road maintenance operations.

Year	Total amount of salt [tons]	Total amount of gravel [tons]
2007	7.147	7.291
2008	19.845	15.673
2009	19.478	14.816
2010	19.201	n.a.
2011	13.494	n.a.
2012	10.984	n.a.

Table 23: Total amount of de-icers used in winter road maintenance activities.

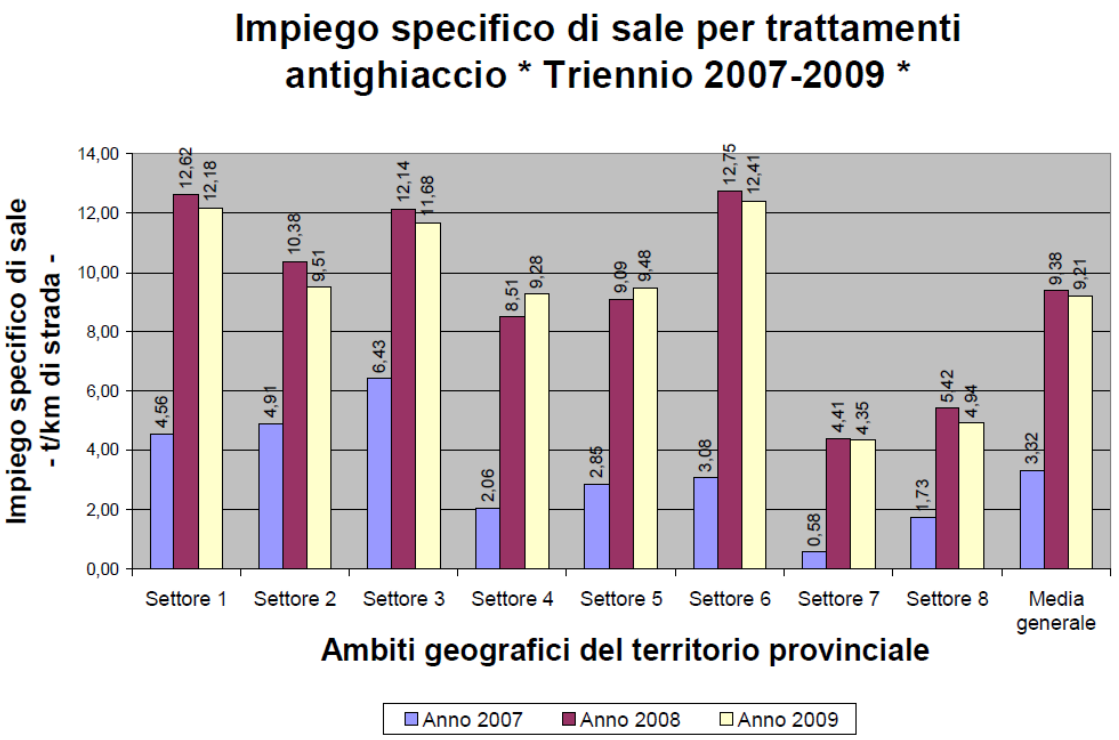

Figure 25: Salt per kilometer used in winter road maintenance activities in different geographical sectors [8].

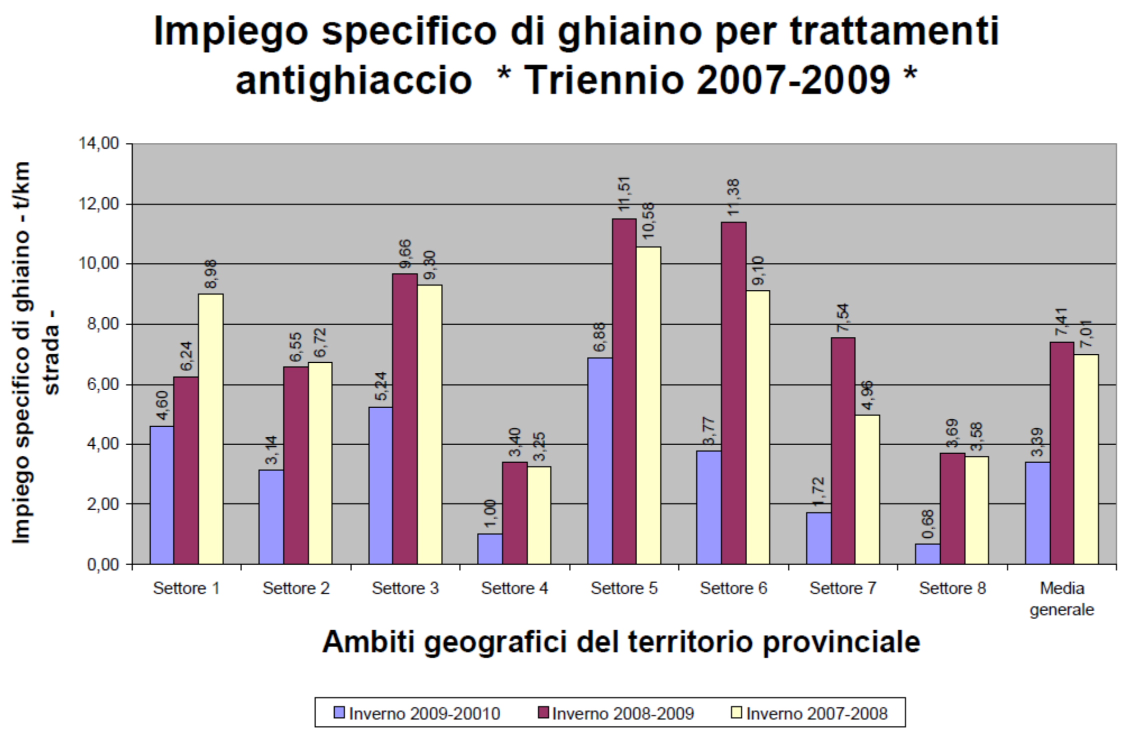

Figure 26: Gravel per kilometer used in winter road maintenance activities in different geographical sectors [8].

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 Euro**, which is a quantity which is destined to increase in the near future because of the continuous increase in its price. The reduced financial capabilities of public administration will also probably force them to reduce the quantities of salt that they can have at disposal for this kind of activities.

The Province of Trento doesn't have internally all the human and hardware resources to perform the winter treatments; this is the reason why part of the work is outsourced to external companies. **About 300 workers are employed internally for these operations**; they are divided in 60 groups, and devote on average 65% of their time for anti-icing treatments and 45% for the snow removal activities. In order to optimize the daily work of all the employees, the regional road network is divided in stretches of 8 – 12 [km] of length, and for each of them a specific group of road operators as well as all the necessary equipment (maintenance vehicles, etc.) is assigned already at the beginning of the winter season. By 2010, the whole fleet at disposal of the Road Management Service included:

- 270 trucks or tractors;
- 260 snow remover blades;
- 240 salt or gravel spreaders;
- 30 snow-removing machines;
- 50 tools for snow removal operations.

Figure 27: A glance to the maintenance vehicles' fleet in charge of the Road Management Service of the Autonomous Province of Trento.

Apart from the aforementioned regional yard, which is available 24/7 for every inconvenient, other delocalized area are at disposal for the storage of vehicles and equipment, namely:

- 72 garages, that are able to store more or less the 50% of the vehicle of the fleet;

- 39 plant silos used to store the salt;
- 60 protected and fitted warehouses that are able to store salt and gravel.

Figure 28: The plan silos near the road inspection's house in correspondence of the test area of CLEAN-ROADS.

3.1.3 Current winter road maintenance procedures

During the winter season (which typically extends at maximum from October to April) a permanent **24/7 road surveillance service** is activated. All road operators contribute, in turn, to the executions this service, even (and above all) during the nocturnal periods and the week-ends. When in turn, road operators have the responsibility to continuously check the meteorological conditions and alert his colleagues in case of need (e.g. a snowfall is approaching, an ice formation event is probably taking place). The leader of the road operators' team must then take care of the situation and decide how the treatment must take place (who is involved, when and where the treatment must be applied, in which term, etc.) This service involve on average fifty road operators, which alternate in this task every week. During ordinary operations, road operators are used to go on patrol on the road stretch of competence. This empirical assessment trip is performed at 5:00 AM with the purpose to check the effective conditions on the road and to eventually treat it in case of necessity. In case of snowfall, a proactive treatment is typically performed, and snow removal operations only start when the snow height is becoming higher than 5 [cm]. Variable Message Signs start to provide messages to the local travelers about the proper behavior to follow, as well as other traveler information service (e.g. “Viaggiare in Trentino”).

In the past years, intense snowfalls determined relevant traffic disruptions, mainly caused by improperly equipped vehicles (both private and commercial) in circulation. For this reason, the Province of Trento decided during the winter season 2005-2006 to introduce a reference **emergency coordination plan**, shared among different public organizations (i.e. the Road Management Service, the Civil Protection Department, the Weather Service, the Forest Service, the Municipal Polices, the Law Enforcement Agencies and the Fire Brigades), for the definition of the specific procedures to be followed in case of intense snow events, and whose aims are to:

- monitor the traffic condition in correspondence of important road sections or intersections (e.g. intersections between congested roads, in proximity of important mountain passes and/or ski resorts, etc.);
- collect information about the roads’ conditions;
- provide useful information to the drivers;
- prevent and solve critical situations;
- guarantee an efficient assistance to drivers who find in troubles.

In order to ensure this, twenty check points have been specified. During the snow event, the check points must be continuously controlled by human beings and supervised at a central level (Figure 29).

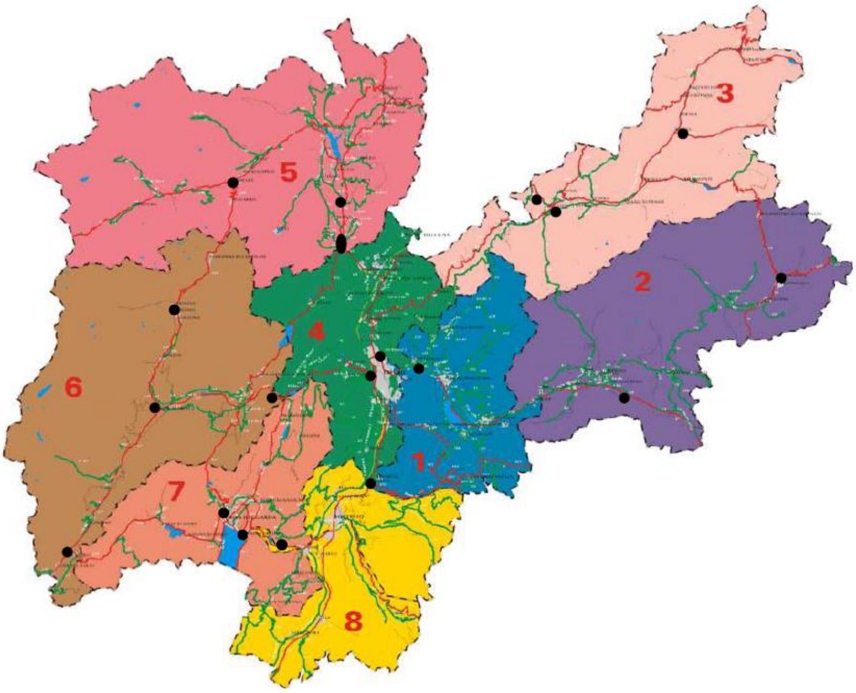

Figure 29: The location of check points that are activated in case of actuation of the local emergency plan.

Two alerts situation have been defined, namely:

- **first level alert**: this level is activated if the weather forecasts predict with a probability greater than 50% snowfalls with intensity of more than 10 [cm] per day in the lower valleys (i.e. under 500 [m] of altitude);
- **second level alert**: this level is activated much more intense snowfalls are predicted (more than 50 [cm] in the lower valleys).

The overall coordinator of the Road Management Service is in charge to assess the possible impact of snowfalls on the local road network. During the whole emergency a **permanent operating centre** is activated jointly with all the different organizations involved. This centre continuously monitor the overall situation and provides the decided guidelines to all the different human resources who are involved in the supervision of the check points and in the snow removal operations. Traveler information systems (e.g. VMSs, the on-line portal "Viaggiare in Trentino") are regularly updated during this phase as well (Figure 30).

Figure 30: The on-line portal "Viaggiare in Trentino" (source: viaggiareintrentino.it).

3.1.4 Preliminary quantitative inefficiencies assessment

A preliminary quantitative assessment of the road maintenance activities has been carried out during the winter season 2012/2013, in partnership with the preparation action A1 [7]. Because of the delays encountered in the first project phase, only part of the ex-ante assessment activities were carried out during this winter season; these will be significantly extended and detailed during the winter season 2013/2014, according to the recovery plan shared and approved by the European Commission, and will give the possibility to confirm several specific inefficiency aspects which have already emerged during the first winter season analysis. This preliminary assessment activity has been mainly carried out through a detailed evaluation of the winter road maintenance activities carried out in the test area of the CLEAN-ROADS project, namely a stretch of the route SS12 of about 18 [km], which connects the local village Lavis to the regional boundary with the Autonomous Province of Bolzano in the locality Salorno [9]. This data, manually recorded by the road operators and pre-aggregated by their team leader, has been then correlated with the meteorological data acquired a weather station not far from the test route, which is located in the locality San Michele all'Adige, in order to preliminary estimate and quantify the potential number of avoidable (or missed) treatments. For a detailed description of the considered correlation methodology as well as of the results obtained, please refer to deliverable D.A1.3 [7]; in this report, we will just provide the main outputs of this work with the goal to put in evidence the different inefficiency aspects which may be targeted through the CLEAN-ROADS system.

It is also worth noting that the road operators team in charge of road maintenance activities in the project test area have manually recorded their operations since 1998, and all this just for themselves, with the aim to continuously improve the service they are in charge to provide. All this represents a plenty of information of priceless value for the project, since this can offer a much more broader perspective of the targeted problems over the different years. A summary of all this dataset is offered in Figure 31, where the total amount of salt, the number of treatments and the average quantity of salt per sample road area (expressed in [g/m^2]) are directly put in relationship with the amount of snowfalls recorded in the area. It is worth noting that the data are presented on a year basis, this means that the data of two different winter seasons (e.g. January/February/March and November/December) are aggregated together.

The data show that obviously the highest amount of salt (and number of treatments) are registered during the snowiest winter seasons (e.g. 2008), but this is not always the case, as a demonstration of the relevancy of ice formation avoidance activities (e.g. during calm nights and high humidity) in a low altitude area like the one under investigation. Because of this, the average amount of salt spread per square meter is more or less always in the order of 4-5 [g/m^2].

A <u>first inefficiency</u> that in our view can be very significantly reduced through the CLEAN-ROADS system is the one related to the **"unnecessary" amount of Vehicles Kilometers Traveled (VKT) by road maintenance vehicles**. In fact, as already mentioned, the actual procedure is to go on patrol in the early morning to check the effective conditions on the road and to eventually treat it in case of necessity; for the case study road, this is typically carried during the period November 15th – March 15th. Table 24 provides a direct comparison for the winter season 2012/2013, in which this aspect was specifically assessed and also quantified in economic terms (by considering a very conservative standard ACI tariff of about 0,5 [€/km]). This very preliminary estimate, that needs to be further assessed during the winter season 2013/2014, as well, <u>state on average about the 50% of trips are avoidable</u>, i.e. they not produce any effective treatments on the road. This percentage is of course higher during the milder months, were the probability that the road needs a treatment is significant lower; the lowest optimization margins are located on the contrary during colder months and above all in correspondence of snowy events. By considering the fact that the economic saving is related to a road stretch of about 15 [km] only, one can quickly foresee the order of magnitude of savings along all the road network, at least for that part which is located at lower altitudes. It is also worth noting that these figures do not take in any consideration the waste of time by road operators, that could be destined to other useful activities: considering that every trip has a duration of about one hour and in the conservative hypothesis that it involves only one road operator, about 78 hours could be saved (i.e. more or less 3.25 equivalent days of work), or equivalently about 1.170 € (if a reference rate of 15 [€/h] is considered).

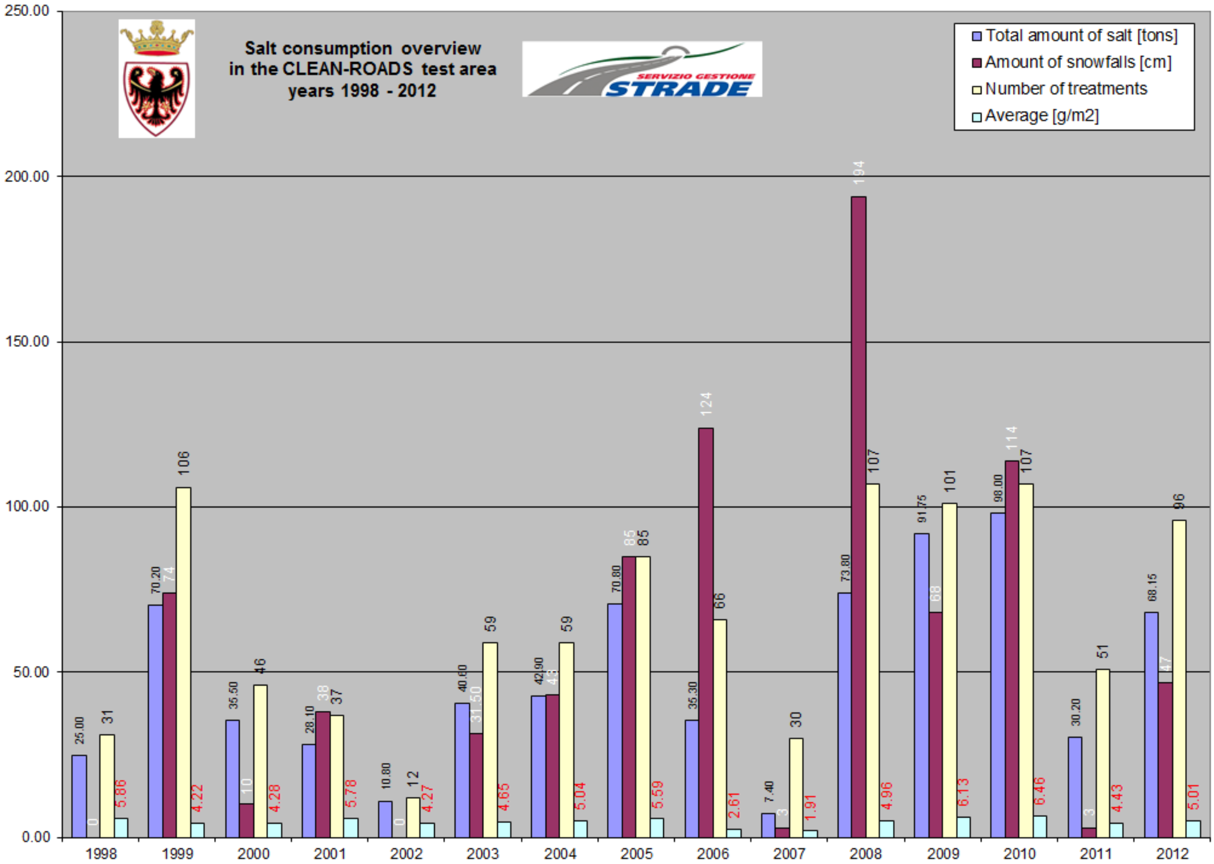

Figure 31: Salt consumption overview in the CLEAN-ROADS test area (year 1998-2012).

Month	Nr. treatments	Nr. trips	% Avoidable trips	Avoidable km	Cost savings
November 2012	1	16	93.8%	447	€ 223.50
December 2012	41	49	16.3%	238.4	€ 119.20
January 2013	14	32	56.3%	536.4	€ 268.20
February 2013	7	29	75.9%	655.6	€ 327.80
March 2013	2	17	88.2%	447	€ 223.50
TOT	**65**	**143**	**54.5%**	**2324.4**	**€ 1,162.20**

Table 24: VKT avoidance preliminary assessment.

But how many of these avoidable trips are effectively recognizable in advance through a RWIS? How many of these situations are not characterized by a high level of uncertainty of the road conditions, which may make inevitable a patrol operation for safety reasons? On the other side, it may not be sure that all systematic ice prevention treatment activities are really necessary. How many of them can effectively avoided? And furthermore: are there any missed alarms, despite this redundancy of human observations?

In order to provide an initial quantitative answer to these crucial questions, road treatments have been compared to an estimation of the road conditions and the potential necessity to spread salt in order to decrease the freezing point on the road surface. These rough estimations are based, as already mentioned, on the meteorological data gathered by the weather station of San Michele all'Adige, and on parametric post-processing elaborations which are based on considerations and relationships of physical nature. For more details on the proposed evaluation model, please again refer to [7]. The outputs of these elaborations have highlighted three possible inefficiencies, listed in order of priority:

- **inefficiencies in "systematic" de-icing treatments**, which typically take place when the road surface temperature is going to be lower than the dew point value; in a relevant number of cases, the estimations have revealed the uselessness of some de-icing treatments, in particular when the gap between the above parameters is sufficiently high; moreover, in some cases there could have been the opposite phenomenon of a "missed" alarm, but this aspect should be directly linked to the obvious limitations of the proposed model (e.g. the effect of salt has not been take in specific account) and needs furthermore to be assessed;
- **inefficiencies in proactive operations anticipating a snowy event**, which are crucial for minimizing the amount of salt to treat the road – the right choice of the right time when applying the right treatment is here crucial at most. The preliminary data set has revealed that often this class of treatments takes place in a suboptimum situation, thus producing an increase in the overall treatment resources;
- **inefficiencies in post-snowfall treatments**, which typically take place during the evening in order to avoid that the residual snow on the road can quickly transform into ice. In this case, the optimization margins reveal to be slightly narrower, because in most of these cases these kind of treatment is inevitably necessary.

At the base of these inefficiencies it is possible to immediately associated **a lack of knowledge** about the conditions of the road surface temperature and other important parameters such as the dew point. It is moreover worth noting that typically the **type of treatment** is considered **the same for all the road section**, apart for some sporadic change which e.g. may take place in correspondence of its cold points. This is also a suboptimal choice, since different microclimates can generate different conditions on the road surface and thus be targeted with localized treatment choices.

All these inefficiencies are caused by a main background inefficiency, i.e. the **lack of a structured decision base** system which can support the road operators in two major tasks, namely (i) the continuous monitoring of the road weather conditions and forecasts, and (ii) the definition of the treatment(s) action plan to be carried out. The first task is at present carried out in an unstructured way by evaluating disaggregate data sources, and all concerning weather conditions and forecasts (i.e. without any information about road conditions). This is also the reason for very inefficient use cases, i.e. **during night**, when the road operator in charge of the surveillance service needs to continuously monitor these channels in order to detect in time possible dangerous situations. The second task is at present managed primarily on the experience of the responsible of the road operators' team. The inefficiency there is not in terms of quality of service, but is more "structural", since the efficacy of the road treatments depend only on the **competences of the road maintenance staff**, and these are not sufficiently supported by quantitative data that can simplify and justify their decisions. Also the **coordination with other road maintenance organizations** (e.g. municipalities, the A22 highway) is mainly based on the personal relationship between individuals, more than a structured set of tools and procedures for the reciprocal exchange of dynamic information. This personal experience is also related to the subjective knowledge of the cold points, and the absence of quantitative surveys of their effective existence and locations.

A final inefficiency is the one related to the **lack of any recording systems that can keep trace of the road maintenance treatments**. This is quite a relevant aspect, not only for internal service reasons but in particular for demonstrating, in case of necessity, the efforts made for guaranteeing the highest level of road safety.

An overall presentation of the detected inefficiencies, classified and linked on the base of their position in the decision-making process chain, is presented in Figure 32. A perspective of their correspondent optimization margin is moreover summarized in Table 25.

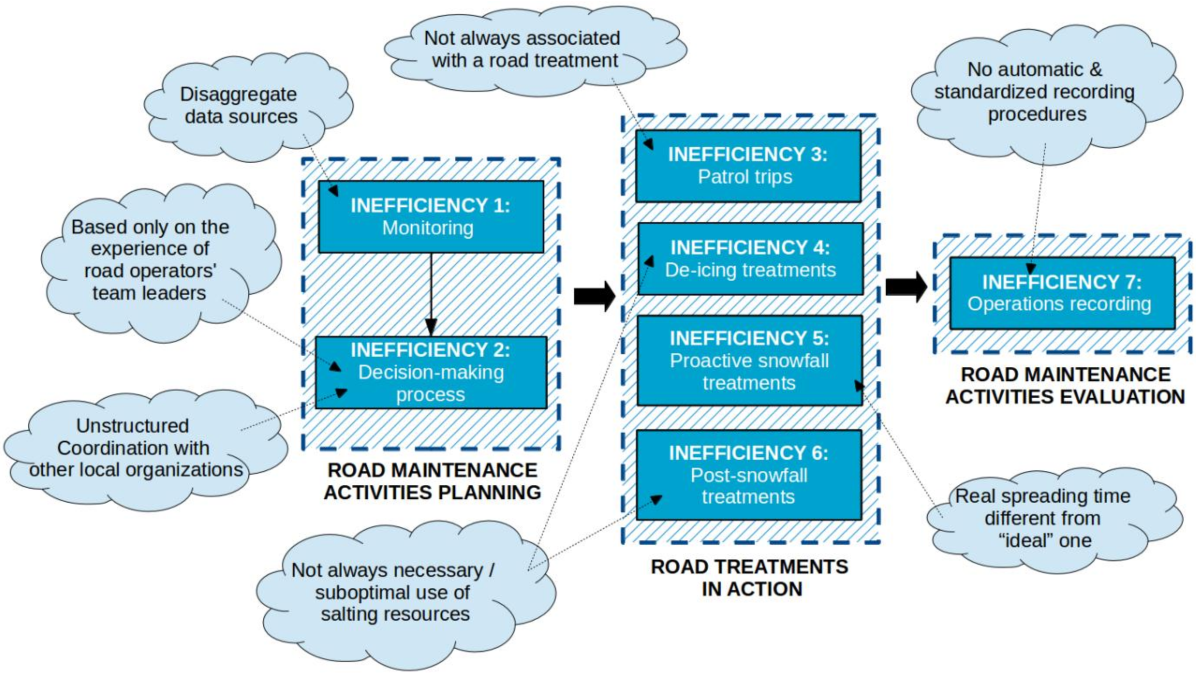

Figure 32: A comprehensive glance to the inefficiencies in the road operators' activities.

ID	Title	Description	Optimization margin
INEF_1	**Road weather conditions monitoring**	Based on disaggregated data sources, road conditions data are not available	High
INEF_2	**Decision-making process**	Relies only on the experience and competence of the road maintenance staff. Suffers of unstructured coordination with other local organization.	High
INEF_3	**Patrol trips**	Not always associated with a road treatment	High
INEF_4	**De-icing treatment**	Not always necessary / to be carried out with less salting resources	High
INEF_5	**Proactive snowfall treatments**	Real spreading time different form “ideal” one	Medium
INEF_6	**Post-snowfall treatments**	Not always necessary / to be carried out with less salting resources	Low
INEF_7	**Operations recording**	No automatic & standardized recording procedures	High

Table 25: Set of road operators’ targeted inefficiencies with prioritization.

3.2 Inefficiencies in the winter travel choices

As far as the inefficiencies in the winter travel choices is concerned, the plenty of indications coming from the user needs’ analysis has been directly matched with quantifiable traffic and meteorological data in order to specifically assess and weight the presence (or not) of some inefficiency on the local roads during the winter season. The main questions that have lead this analysis have been the following:

- how many local travelers decide to avoid a car trip during bad weather conditions, and how is mobility demand influenced by precipitation events?
- are bad weather conditions the reason for traffic jams during winter? And if yes, what is the relevancy of these congestion phenomena?
- do drivers show any significant variations in their driving style during bad weather conditions, and to what extent?
- is road safety really a minor issue for the local road network, thanks to the high quality of service guaranteed by the road maintenance staff?

3.2.1 Preliminary quantitative inefficiencies assessment

In order to give a proper answer to all these questions, the traffic data gathered by a fixed traffic detection system installed within the case study route has been considered. This detection point is located in correspondence of the small village of San Michele all’Adige, a point of the road network where, despite actual legal urban speed limits of 50 [km/h], is typically above 60-70 [km/h] because of the high capability of the roadway. The decision to consider this point for these analyses is also referred to the fact that it is quite near (i.e. a couple of hundred of meters) one of the main local traffic bottlenecks, i.e. a very narrow bridge connecting to the west side of the town where the access to the A22 highway as well to other arterial roads in direction to several local valleys is located (Figure 33). This point is inevitably the reason for several traffic jams in the area, which should be in some extensions be detectable also by the traffic detection station. So, this point offered all the potential for jointly assessing, directly in the case study road, all the different aspects which are under evaluation.

Figure 33: The location of the traffic detection point considered for the analysis of the local travelers inefficiencies.

Traffic data has been available with a resolution of one hour, and classified as a function of the monitored vehicles' speed. The classification in use assigns a vehicle to one of ten predefined ranges of amplitude of 10 [km/h], and the type of vehicle (in the analysis only heavy and light vehicles categories have been considered for simplicity sake). This data was aggregated in both direction of travel, since it was not the scope of this analysis to evaluate differences with respect to this factor, and directly correlated with the precipitation data of the weather station considered already for the evaluation of the inefficiencies of the road maintenance activities, and which presented the same temporal resolution. For simplicity reasons, the analysis has been focused only on the month January 2013, which is typically the worst period in terms of climatological rigidity and snowfall events.

The first analysis was focused on the **evaluation of daily traffic levels**. A scatterplot of light and heavy vehicles values has been computed for all different days, and labeled as a function of the type of the day (working / non working) and the precipitation levels occurred (normal; quasi normal / rain; snow / before snow). The results are presented in Figure 35, and show different interesting insights, namely:

- **traffic reductions are clearly visible during snowfall events**, but only if the mobility demand is relatively low, i.e. snowfalls occur on days where most of the people can take the decision to avoid a trip, and the intensity of the precipitation event is sufficiently high to induce travelers for similar decision. This phenomenon is much more evident during non-working days, in which the mobility demand is much more free and less forced by external commercial factors. Traffic reductions are in the order of 20-30% of the entire daily volume during working days, and can arrive even to 50% during non-working days;
- because of the aforementioned considerations, **traffic reductions are more likely to affect light vehicles than heavy ones**;
- precipitation events different from snow (i.e. **rain**) can on the contrary determine an **increase in traffic volumes**, especially during working days and in particular as far as light vehicles is concerned. This may be a consequence of the fact that many people decide to change travel mean in these circumstances, and prefer their most comfortable car e.g. in order to avoid delays, get wet, etc.

A first (obvious) inefficiency can be therefore individuated, namely the impossibility to have “conventional” traffic levels even during bad weather conditions. The impact of these reductions are a function of both the current mobility demand and the intensity of the weather event, as it is possibly to see in Figure 34, which clearly puts in evidence how weather events may (or may not) negatively affect traffic levels.

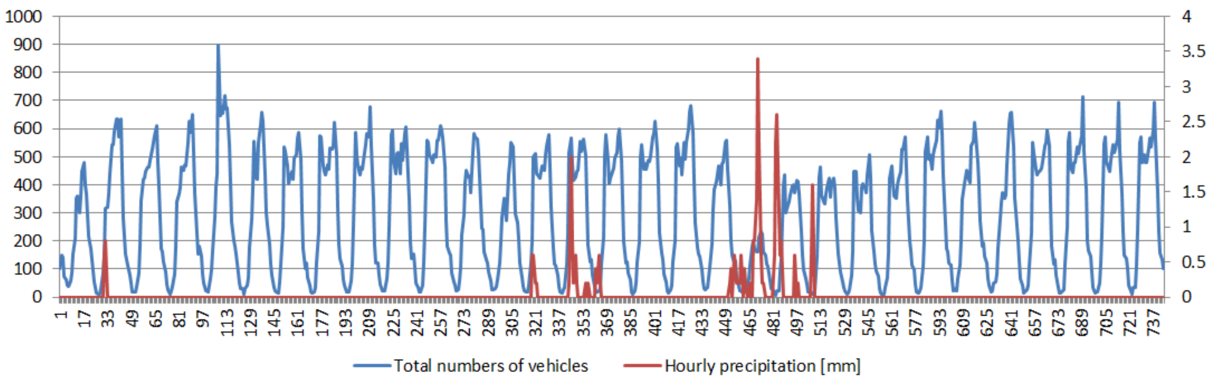

Figure 34: Hourly precipitation correlated with vehicular detections.

The impression is however that when the first factor is high, traffic levels tend to be reduced only in part, independently of the quantity of snow which may fall on the road. These may be the cause for a second relevant inefficiency, probably worse than the first one, i.e. the creation of traffic jams. In order to assess this, the hourly traffic data has been directly processed in order to compute a **reference congestion index** $C.I.$, defined as:

$$C.I. = \frac{card(M)}{N}$$

[1]

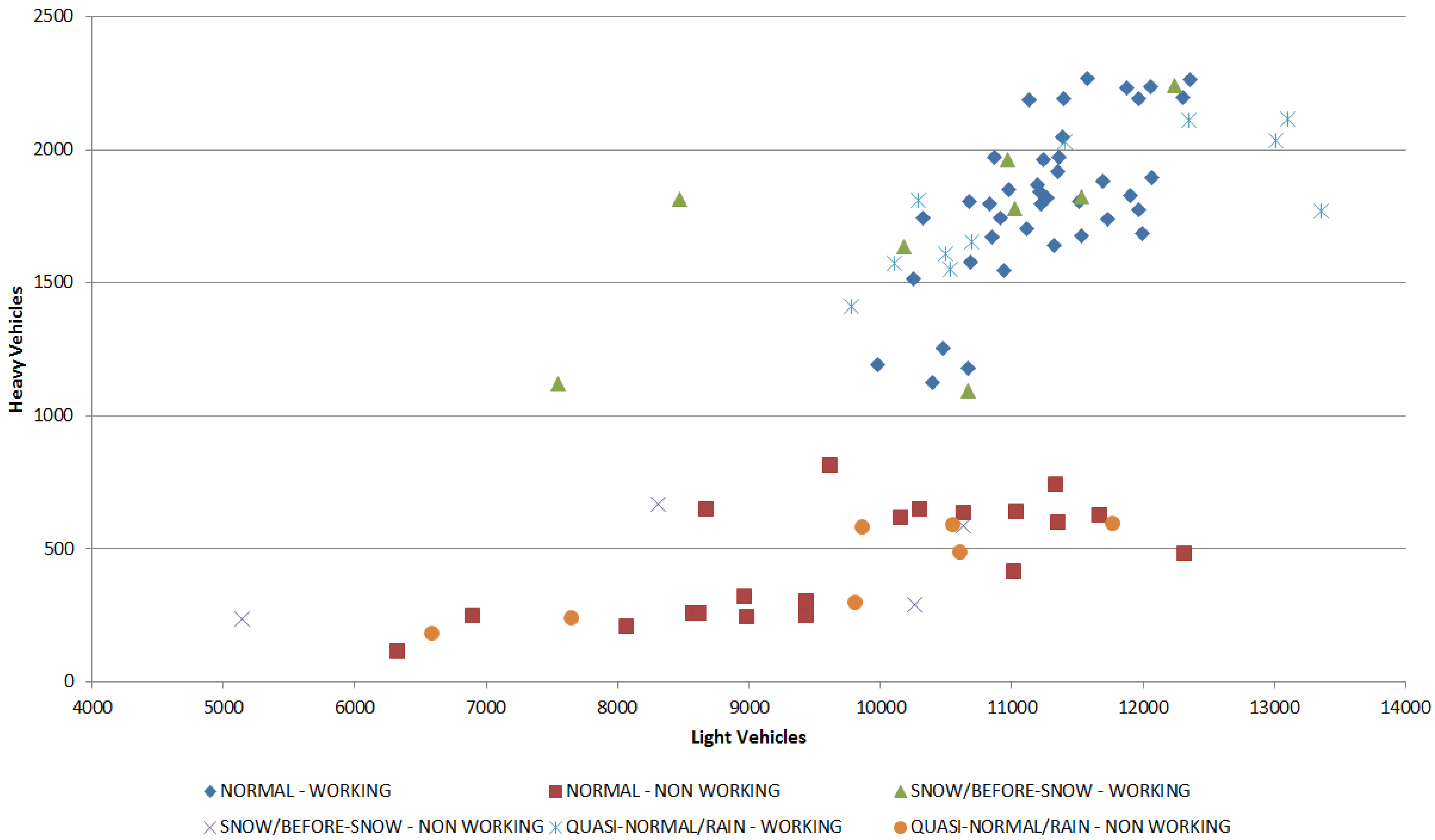

Figure 35: Light and heavy vehicles daily traffic values scatterplot compared with weather events.

where $card(M)$ is the cardinality of the set M which is defined as the set of vehicles passing from the detection point with a speed v which is lower than a reference threshold speed v_{th}, and N is the total number of detected vehicles. Because of the peculiarities of the monitoring area, the parameter v_{th} has been set to 40 [km/h]. Congestion index and hourly precipitation data have been plotted together in Figure 36, and clearly show that a relevant traffic jam has occurred during the most intense of snowfall occurred in the month, as a demonstration of the previous consideration. Data reveals that the traffic peak is located just at the beginning of the snowfall, which may mean that this could have been generated by plenty of travelers wanting to anticipate their travel. The intensity of this jam is not irrelevant – 25% of $\mathrm{C.I.}$ means that during an hour a quarter of all vehicles passed at a very reduced speed, and is moreover not that isolated in time domain.

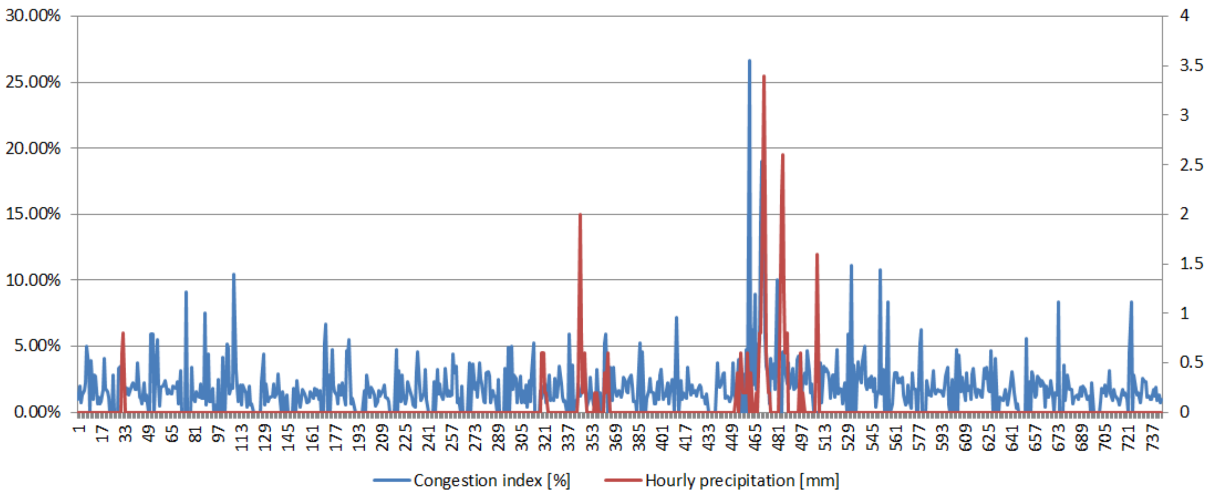

Figure 36: Hourly precipitation correlated with congestion index.

Finally, what about the **driver behavior optimization** in correspondence to these weather events? The answer to this question is directly provided in Figure 37. Apart of the evident reductions during the most intense snowfall – but caused by the previously detected traffic jam, <u>no evident and significant behavioral changes are likely to be identified</u>. This is in some way a quantitative confirmation of the impressions provided by local travelers, i.e. drivers have a very reduced responsibility on the roads and have typically a very high expectation towards the road maintenance service. On the other side, this directly states that roads present very reduced decreases in their nominal capabilities, and this is a direct consequence of the efficient snow removal operations that are already in place which have also the effect to guarantee very high safety levels. This is further demonstrated by the **accident data** provided by the local law enforcement agencies, integrated with the rescue operations information shared by ACI: during the winter season 2012-2013, <u>only one accident has taken place in the case study road, and not because of suboptimal road surface conditions</u>. This information is generally confirmed for the whole Autonomous Province of Trento: accident caused by bad weather conditions in winter represent only a small percentage of the total. It is worth noting that this data source does not take in consideration little accidents, which do not require either the intervention of the local police or the road rescue: these events can more often take place in this season, in particular at low altitudes where most of the “inexpert” drivers are used to travel, and are the reason for several controversies with the Road Maintenance Service.

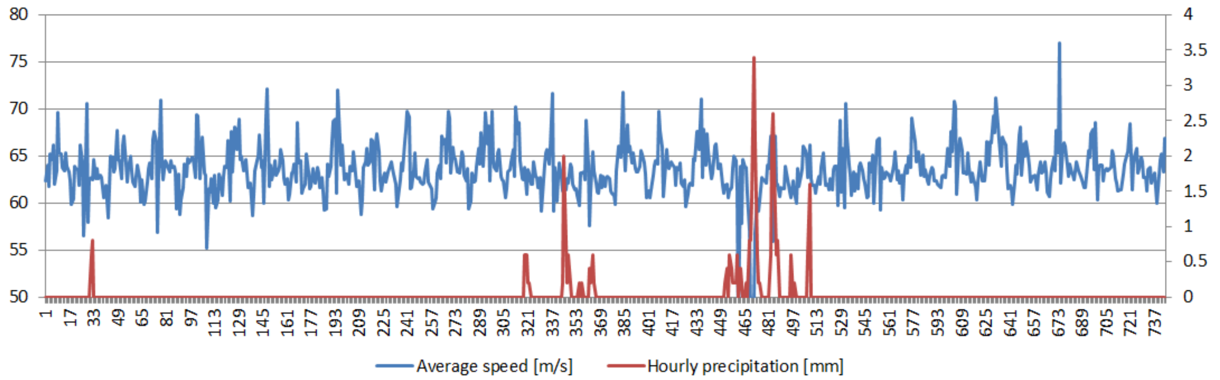

Figure 37: Hourly precipitation correlated with average speed.

In conclusion, this specific data analysis activity has allowed to get confirmation of the several indications gathered in the user needs’ evaluations, and to quantify a prioritize the set of inefficiencies listed in Table 26. Similarly to what was done at the road maintenance side, “direct” inefficiencies (i.e. observed on the field) are matched with “indirect” inefficiencies (i.e. not observable on the field but which are the main reason the observed one), as shown in Figure 38.

ID	Title	Description	Optimization margin
INEF_8	**Traffic levels**	Intense snowfalls have the effect to significantly reduce the typical traffic levels on the roads. This is much more evident when the mobility demand is low.	Medium
INEF_9	**Traffic jams**	In correspondence of relevant traffic levels matched with significant weather events, very intense traffic jams can occur.	High
INEF_10	**Speed adaptation & drivers’ behavior**	Drivers show to change only in very little part their speed and in general their driving behavior, independently of the weather conditions.	High
INEF_11	**Road safety**	Accident data state that road safety in winter is not a major issue for the region, and this results should be maintained or eventually improved in the near future.	Low
INEF_12	**Drivers’ education & equipment**	Suboptimal travel decisions and attitudes during the winter season are a consequence of low travelling education, which is more relevant for “occasional” drivers (including e.g. tourists).	High
INEF_13	**Traveler information services**	Despite the availability of different traveler information services (including weather information), these instruments seem to be not sufficient for taking optimal travel choices.	Medium

Table 26: Set of local travelers’ targeted inefficiencies with prioritization.

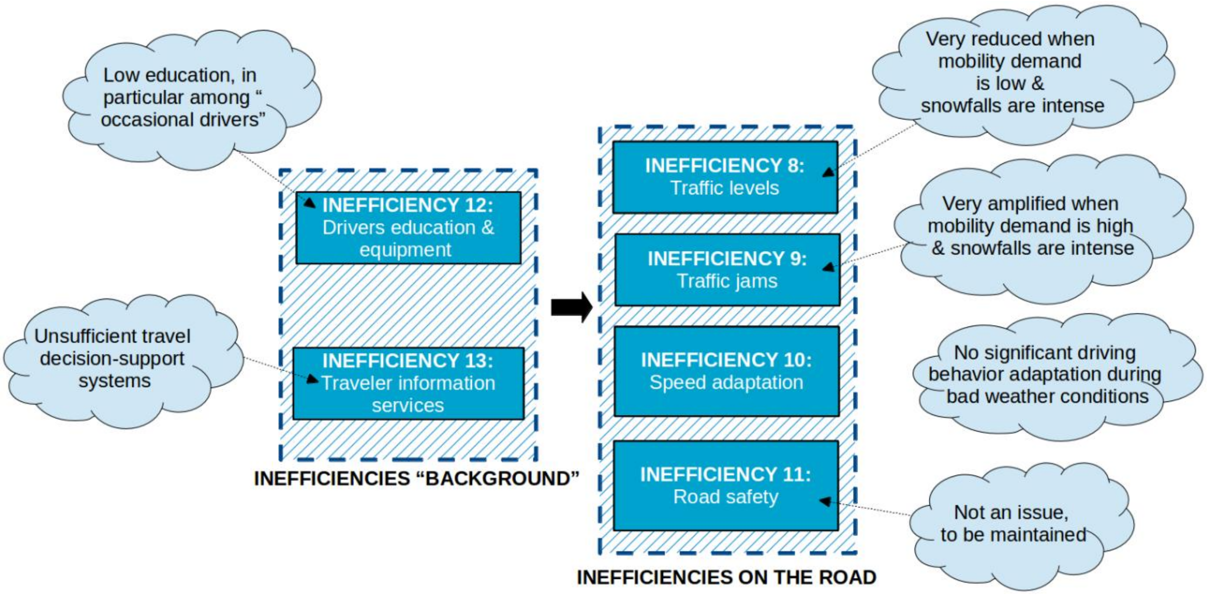

Figure 38: A comprehensive glance to the inefficiencies related to local travelers.

4. Use Cases

Chapter 3 has put in evidence the main inefficiencies which are observable on the local regional roads, and thanks to a preliminary comparison with reference data, which will need to be further assessed during the next project winters, it has been possible to determine the relevancy of such inefficiencies and thus the potential to improve them, in particular through technological instruments such a RWIS. The objective of this Chapter is to make a step forward in this process of analysis of the user requirements by identifying a set of reference use cases, targeting both road operators as well as local travelers. **Use cases** have become a common practice for assessing functional requirements, not only in the software design domain, where they originated, and are defined as "*a goal-oriented set of interactions between external users and the system under consideration or development*" [10]. Use cases typically refer to **use case scenarios**, which are "*idealized descriptions that can include stories, examples, and drawings and aim at illustrating, step by step, how a user is intending to use a system, essentially capturing the system behavior from the user's point of view*". The main added values of introducing use cases during the initial phase of a complex ICT-based project such as CLEAN-ROADS is that they are extremely useful for describing the targeted problems in unambiguous terms and are therefore in condition consolidate a common view of what the system will do (and won't do), not only among project partners but also, if applicable, with the end-users as well.

In the next paragraphs the CLEAN-ROADS reference use cases are presented. They will specifically consider the main situations of inefficiencies and the current use case scenarios, and propose their possible evolution thanks to the innovations proposed by the project. Use cases are directly linked with the user needs identified in the first step of this requirements' analysis process, in correspondence of which numerous starting points for most of them were provided.

4.1 Road maintenance activities use cases

The use cases which refer to road operators are linked with inefficiencies INEF_3, INEF_4, INEF_5 and INEF_6, that are immediately connected to the road treatments "in the strict sense", namely when they are applied on the road infrastructure. Use cases do not directly consider the other inefficiencies (i.e. INEF_1, INEF_2 and INEF_7), but are all in indirect relationship with them: indeed, road operations (i) necessitate of preliminary monitoring activities and a decision-making process, following the consolidated procedures which are actually in place, and (ii) are directly linked to recording activities which have the purpose to keep trace of them. A comprehensive overview of the road operators use cases is given in Table 27, which includes a direct matching with reference inefficiencies and a description of the actual typical use case scenarios. Proactive snowfall treatments have been divided in two different use cases depending whether they take place at night or during the day, in order to highlight the structural differences in the underlying monitoring process.

ID	Title	Use Case Scenario	Reference inefficiencies
UC_1	**Patrol trips**	During the early morning (typically at 5:00 AM) one or more road operators are involved in a patrol trip on the case study road, independently of the current and forecasted weather conditions (but unless a snowfall is approaching – in this case UC_2 applies). Road operators are in charge to manually check the road conditions in all different points, in particular in correspondence of the cold points, in order to detect the presence of ice on the road. In case of need, a minimal de-icing treatment (5 [g/m^2] salt flux with standardized spreading operation width) is applied, similarly to UC_5. The treatments can be localized if only specific points of the road show ice formation potential, and adapted as a function of the entity of the detected safety issue.	INEF_3
UC_2	**De-icing treatments**	De-icing treatments typically take place during the early morning (e.g. at 5:00 AM), in order to guarantee a high level of road safety during the traffic peaks caused by the morning commuting travels. Differently from UC_1, treatments details (e.g. salt flux amount and spreading operation width) are decided by the leader of the road operators' team and communicated in advance before the patrol trip takes place. Operators on the maintenance vehicle have the freedom to occasionally adapt the parameters of the treatment as a function of the localized road conditions they may encounter during their trip.	INEF_4
UC_3	**Diurnal proactive snowfall treatments**	In case of snowfall events taking place during the day time, all the road operators' team is on the alert and ready to perform proactive treatments in order to minimize the bonding effects that snow can produce when entering in contact with the road. The snowfall event is continuously monitored through the available weather channels (in particular the service provided at regional level) and by eventually contacting, in an informal and unstandardized way, other organizations in charge of the maintenance activities on other adjacent road networks. Based on this limited and disaggregated information, the leader of the road operators decides when to start the proactive treatment (which is the most crucial and delicate decision), in which form it should take place, and from where it should be started. In this case, road operators follow very precisely these instructions. After the proactive treatment, the snowfall event is continuously monitored and snow removal operations (eventually combined with other salt treatments) can follow as a function of the entity of this meteorological event.	INEF_5
UC_4	**Nocturnal proactive snowfall treatments**	In case of snowfall events taking place during the night time, one of the road operators, i.e. the one in turn in charge of the nocturnal surveillance service, must follow the evolution of the snowfall event and eventually continuously coordinate with the team leader. The available channels are the same as described in UC_3. In case of need the road operator wakes up his	INEF_5

		colleagues and the proactive treatments finally start, following the same approach described in UC_3.	
UC_5	**Post-snowfall treatments**	During the evening after a snowfall, typically at 5:00 – 6:00 PM, the road operators' team evaluate the necessity to apply or not a de-icing treatment in order to prevent the formation of ice caused by snow residuals freezing on the road. This decision is mainly supported by manual previously patrol inspections of the road (e.g. snow removal operations) and the weather forecasts provided by different available providers. Based on this limited and disaggregated information, the leader of the road operators decides whether to apply the treatment or not, and in which terms it should be carried out. It is worth noting that this use case may take place even in correspondence of critical nights where ice formation processes can occur already during the early evening (e.g. cold nights with clear sky, calm wind and high relative humidity) and thus putting in danger the road safety of vehicles transiting during this late part of the day. Eventually, a patrol trip can be organized, following the approach described in UC_1.	INEF_6

Table 27: Road operators use cases with matches to reference inefficiencies and actual use case scenarios.

It is worth noting that this set of use cases can be divided in two specific categories, as a function of the part of the day in which the different types of treatment are carried out. An overall picture of how the use cases are temporally distributed within an ideal 24-hours time frame is presented in Figure 39 and Figure 40.

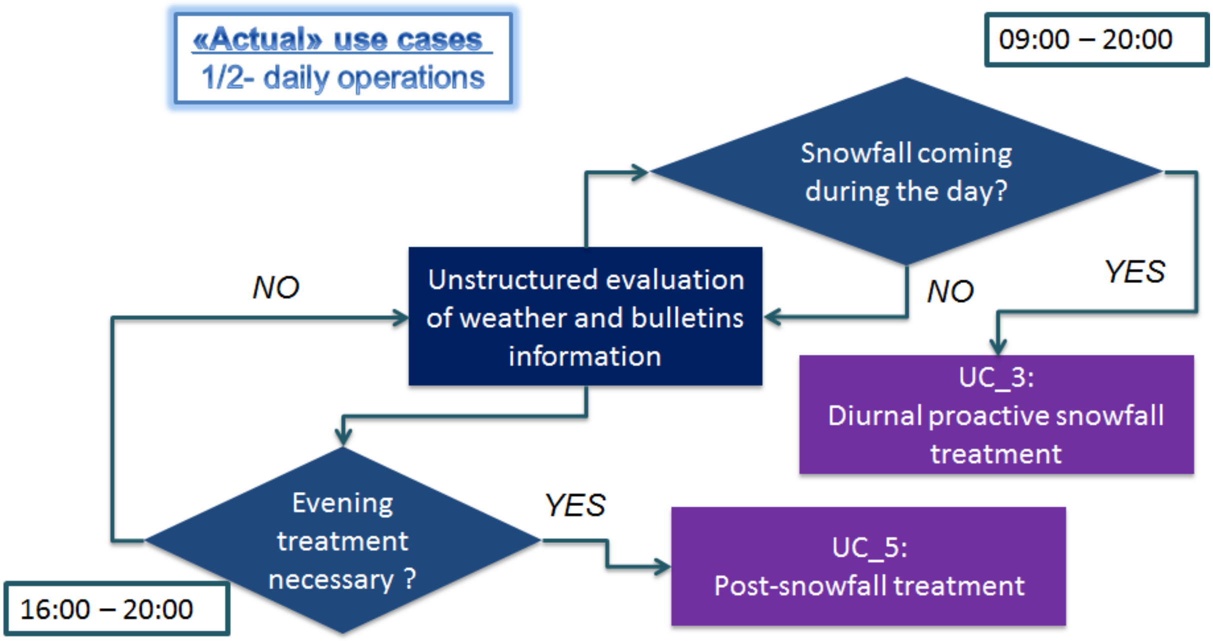

Figure 39: Road operators actual use cases – day time.

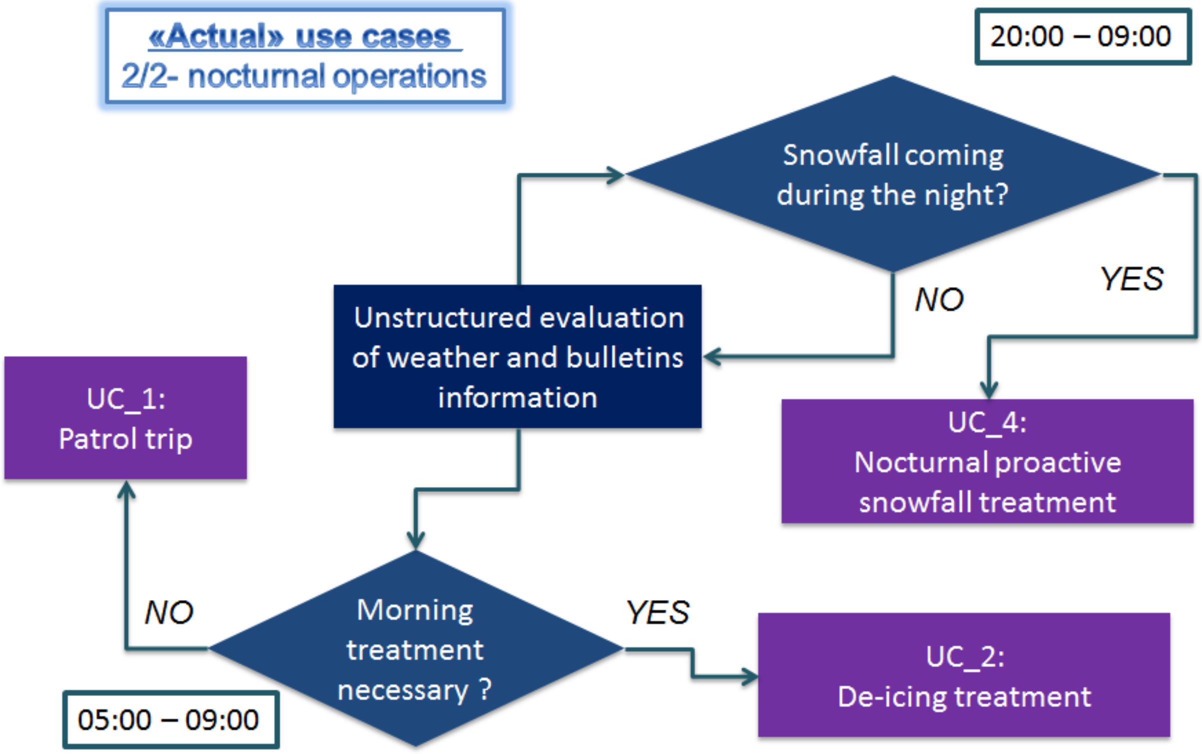

Figure 40: Road operators actual use cases – night time.

The following paragraphs offer a detailed picture of how all these use case cases will evolve through the CLEAN-ROADS system, and try to put in evidence the added value and the benefits that it can produce for the overall improvement of the road maintenance tasks. The use cases description are characterized in terms of:

- **reference use case scenario**, which try to offer a complete picture on how this associated use case may take place in the future thanks to the CLEAN-ROADS system;
- **goal**, which clearly identifies the added value of the innovations introduced in these reference situations, in particular addressing the aforementioned inefficiencies;
- **actors**, which identify the users who will interact with the CLEAN-ROADS system;
- **constraints**, which point out the possible factors which may reduce the impact of the potential benefits;
- **inefficiencies addressed**, which clearly state which are the inefficiencies that are specifically targeted by a use case;
- **exceptions**, which assess the practical limitations on the base of which the end-users may decide to not take in consideration (or only in part) the recommendations offered by the MDSS;
- **main flow**, which graphically illustrates the different steps in which the use case evolves, considering in particular the relationships between the “users” and the “system.

4.1.1 UC_1: Patrol trips

Table 28Table 28 illustrates the evolution of UC_1. The main benefit here is in terms of the possibility to decide in advance if a patrol trip is really necessary, i.e. if there is a non-negligible probability of ice formation on the road which may determine a risk for road safety. It is worth noting that this use case is the one that can lead to the most relevant optimization margins, as stated in the quantitative analysis of the reference inefficiencies.

UC_1	Patrol trips
Reference use case scenario	At 04:30 AM the road operators' team meet at the road inspector's house. They have to decide if it is necessary to carry out a patrol trip and eventually apply a de-icing treatment. They analyze the information provided through the *Graphical User Interface* (GUI) of the *Maintenance Decision Support System* (MDSS), in which they can immediately visualize (e.g. through a color-coded map) the current and forecasted road conditions, where the time horizon should be in the order of 3-4 hours maximum (i.e. nowcast predictions, which have a maximum time horizon of 6 hours). Through this software, the road operators should be also in the condition to check the possibility of some meteorological events (e.g. a snowfall) as well, and properly prepare in case this may effectively take place. The MDSS also provides the specific daily recommendations coming from the Weather Service, and a direct access to the data collected by the static RWIS stations. The simplified plots provided by the GUI are immediately interpreted by the road operators, who are in the condition to properly evaluate them after the continuous educational activities they are obliged to follow. Further localized information gathered by the last trip(s) of the mobile RWIS is also available in case of need. Based on the indications received by the MDSS, and a direct assessment of the current and future evolution of the road weather conditions, the leader of the road operators' team, in cooperation with all his staff, decides whether or not to do the patrol trip, which may take place in any case if the evaluated risk of ice formation is considered too high for not performing it. During the trip, the road operator in charge must activate the automatic operations' recording system on board of the mobile RWIS station, in order to collect spatially distributed data on the case study road and keep trace of his possible treatment activities. These may occur at localized points if the road operator visually detects some ice formation risks on the road which are confirmed by the data which the mobile RWIS station is collecting, which are displayed on a proper on-board monitor designed in order to minimize his distraction. Alerts of some critical road conditions are automatically detected by the system and signaled to the road operator (e.g. through acoustic signals). In case of need, the road operator can stop his vehicle and further interact with the on-board application in order to better understand the revealed risk.
Goal	The goal is to avoid unnecessary patrol trips, and thus minimize the overall environmental impact of road maintenance activities (fuel consumption, salt uselessly spread, etc.) as well the costs related to the them. Through these scenarios, road operators are in the condition to determine very efficiently which type of treatment must be applied in which part of the road network under competence. The earned time of road operators can be destined to other useful activities.
Actors	Road operators.
Constraints	The efficiency of this use case may be suboptimal if (i) the MDSS is not sufficiently accurate and reliable and (ii) the road operators are not in the condition to properly understand the different information and recommendations provided by the system in the limited amount of time and given their limited background competences they have for taking this decision. Moreover, during the patrol trip, the road operator driving the maintenance vehicle can be distracted by the on-board vehicle, and thus not be in the condition to properly carry out his monitoring task. The very

	limited amount of time in which he should carry out localized actions can lead to suboptimal treatment decisions.
Inefficiencies addressed	INEF_3, (INEF_1, INEF_2 and INEF_7)
Exceptions	The decision-making process can be significantly influenced by possible issues concerning the responsibility of treatment actions. In fact, if the road operator feels that a certain road conditions situation may have negative consequences for him from a legal point of view, despite of what the MDSS is suggesting, or worse if he already experienced this kind of situation in the short past, he will consider the recommendation of the MDSS only in part, and carry out his action mainly in order to defend his position.

Table 28: UC_1: Patrol trips.

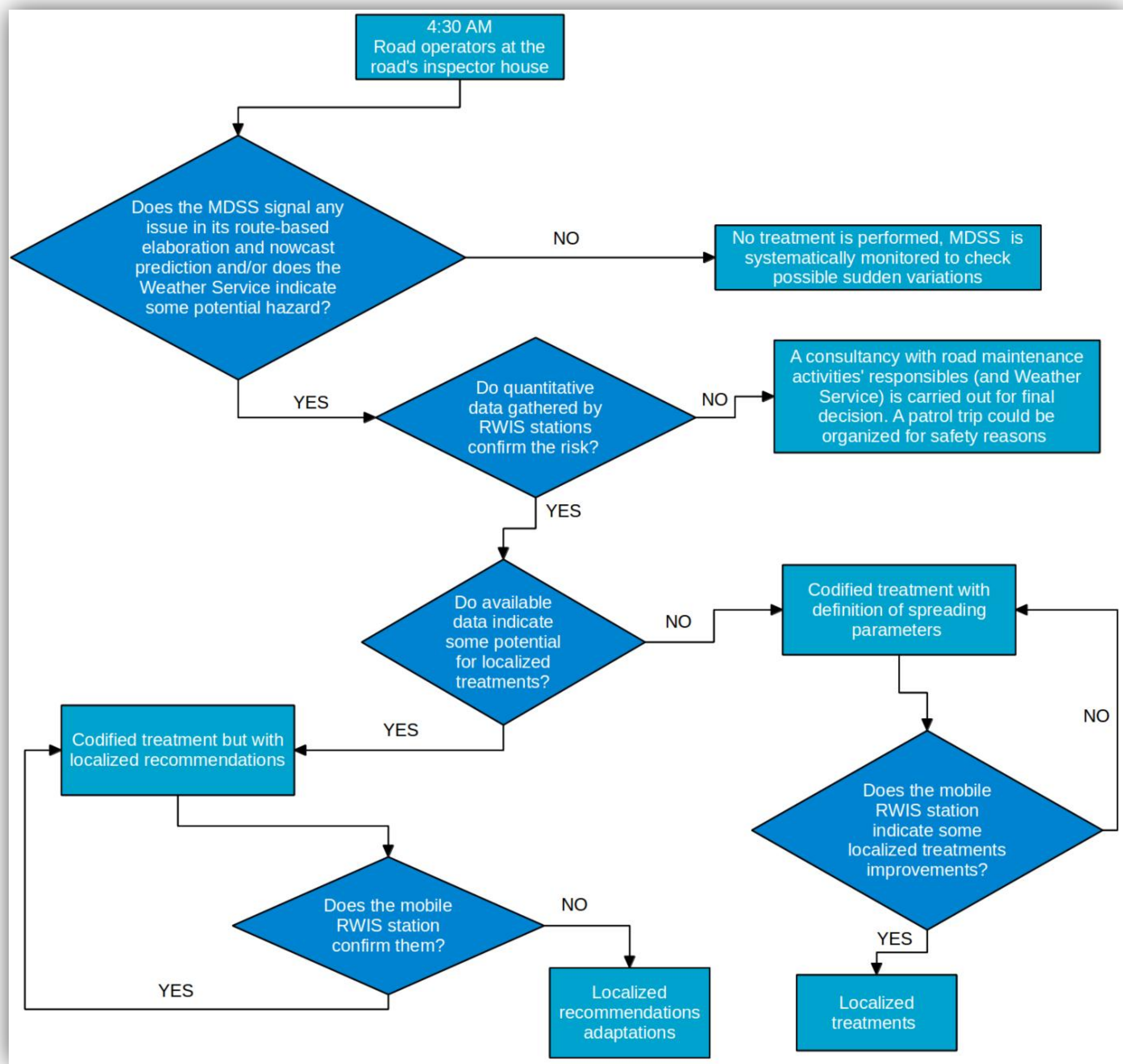

Figure 41: UC_1 main flow.

4.1.2 UC_2: De-icing treatments

UC_2 is very similar to UC_1, as described in Table 29. The main difference here is that the necessity of a de-icing treatment is effectively assessed in advance, and the basic treatment which is decided to carry out can be optimized en-route on the base of the data provided by the mobile RWIS station; indeed a certain treatment can be avoided in localized points if current and forecasted (i.e. nowcasted) conditions reveal this opportunity, and can thus bring to very high levels of efficiency in how salting resources are used. This use case has also shown to have a high optimization margin, since at present it is estimated that a lot of treatments are carried out in unnecessary conditions; on the other side, salting resources can be more wisely destined for covering other potentially dangerous situations that today are associated with missed alarms.

UC_2	**De-icing treatments**
Reference use case scenario	At 04:30 AM the road operators' team meet at the road inspector's house. The road operator in turn, i.e. that has done the nocturnal surveillance service, has already been alerted by the MDSS service that a de-icing treatment in the early morning is recommended. This information is shared in particular with the leader of the road operators' team, which takes his final decision on the treatments' details based on all other available data sources provided by the MDSS as well (e.g. Weather Service recommendations, static and mobile RWIS station data, etc. – see UC_1). During the trip, the road operator in charge activates the automatic operations' recording system on board of the mobile RWIS station, in order to collect spatially distributed data on the case study road and keep trace of his treatment activities. Localized treatments' variations suggestions may be signaled to the road operator through the on-board display, and eventually put in practice.
Goal	The goal is to avoid unnecessary de-icing treatments, and thus to maximize the efficiency on how salting resources are used in order to prevent the formation of ice on the roads and thus guarantee that diurnal traffic flows, in particular during the peak hours in the morning, can take place under high levels of road safety. The optimization takes place not only in terms of unnecessary de-icing treatments avoidance, but also in terms of optimization of the applied treatments, which can be also spatially adapted within the case study road.
Actors	Road operators.
Constraints	The efficiency of this use case may be suboptimal if (i) the MDSS is not sufficiently accurate and reliable and (ii) the road operators are not in the condition to properly understand the different information and recommendations provided by the system in the limited amount of time and given their limited background competences they have for taking this decision. Moreover, during the de-icing treatment, the road operator driving the maintenance vehicle can be distracted by the on-board vehicle, and thus not be in the condition to properly optimize en-route the treatment details. The very limited amount of time in which he should carry out localized actions can lead to suboptimal treatment decisions.
Inefficiencies addressed	INEF_4, (INEF_1, INEF_2 and INEF_7)
Exceptions	The decision-making process can be significantly influenced by possible issues concerning the responsibility of treatment actions. In fact, if the road operator feels that a certain road conditions situation may have negative consequences for him from a legal point of view, despite of what the MDSS is suggesting (e.g. a treatment is not necessary), or worse if he already experienced this kind of situation in the short past, he will consider the recommendation of the MDSS only in part, and carry out his treatment action mainly in order to defend his position.

Table 29: UC_2: De-icing treatments.

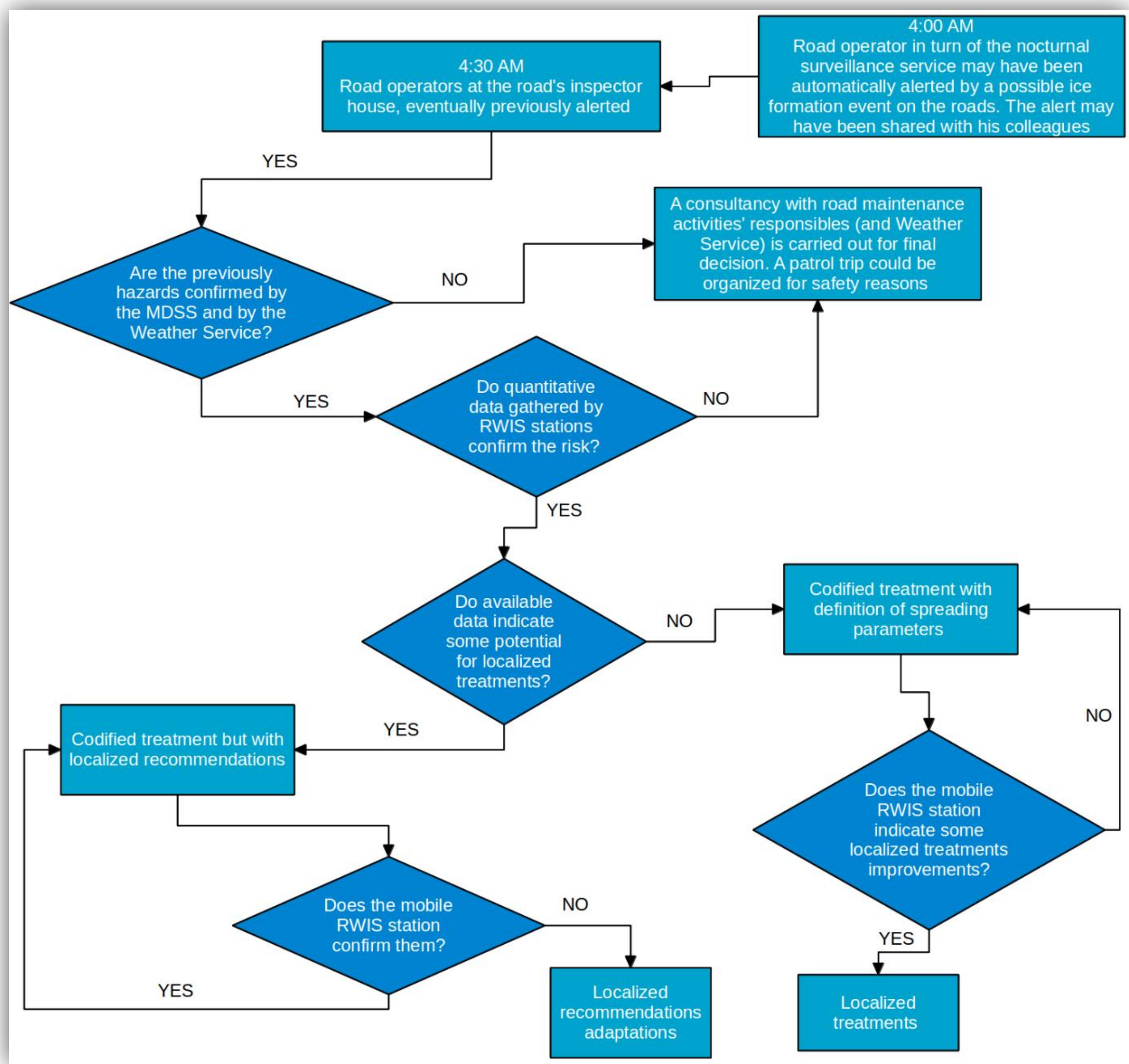

Figure 42: UC_2 main flow.

4.1.3 UC_3: Diurnal proactive snowfalls treatments

UC_3 and UC_4 refer to a completely different situation, i.e. how snowfalls events can be properly managed and addressed. On the contrary to UC_1 and UC_2, which address ordinary winter road maintenance activities, these two use cases have as target the efficient management of extraordinary situations, which typically demand a very high effort by the road operators during the meteorological phenomenon. The optimization margin here is lower than in the previous use cases, because thanks to the standardized procedures introduced by local authorities, the effectiveness of proactive treatments and snow removal operations is already quite high. Despite this, operations are today activated by a unstructured real-time monitoring of the mutations of the weather events through the available online and informal channels (which can also include other road maintenance organizations in charge of other neighboring road networks), and without any information about current road conditions. The CLEAN-ROADS system aims specifically to compensate this lack in the monitoring task by aggregating in a “one-stop shop” application the available data sources, and give specific advices in particular on when and how proactive treatments should take place. RWIS stations can also provide a continuous assessment of the progress of the road conditions, and thus make snow removal operations more effective.

UC_3	Diurnal proactive snowfall treatments
Reference use case scenario	The road operators’ team is in the road inspector’s house following the evolution of the snowfall event approaching the case study road. This monitoring process is based mainly through the MDSS, which provides access to different available channels for monitoring the meteorological conditions (e.g. images gathered by the regional meteorological radar). The MDSS automatically includes information coming from other road maintenance organizations as well, which are exchanged through standardized web-based interfaces. The road operators were already informed about this event by the previous long-term forecasts provided by the Weather Service, i.e. which have a time horizon greater than 6 hours. The MDSS shows the actual route-based road conditions elaboration, as well as the actual data coming from the RWIS stations. In case of need, a preliminary survey with the mobile RWIS station could have been organized, in order to have a very updated overview of the road under control. Based on the evolution of the snowfall, and the nowcast prediction of the road conditions, the MDSS gives its recommendations on when and how proactive treatments should be carried out in order to minimize the risks that falling snow forms immediately a bond with the road surface. The leader of the road operators’ team takes his final decision in coordination with the responsible(s) of the road maintenance activities in the sector of competence, who have also a remote access to the MDSS. Road operators start their proactive treatment and record their operations, collecting spatially distributed data through the mobile RWIS station. Even in this situation, localized treatments can be applied on the base of this latter information source, which indicate this dynamic adaptation through the on-board monitor. During the snowfall event, road operators follow the evolution of this weather from through the available monitoring systems, in particular through the traditional weather channels as well as the static RWIS stations and the information distributed by other road maintenance organizations, without forgetting the last spatial survey carried out by the mobile RWIS station during the proactive treatment. This decision-support base is in particular evaluated by the overall responsible of the road network together by the leader of the road operators’ team, who finally give the proper instruction on how and when snow removal operations must start, and if they have to be combined with a salt treatment. Road operators start the operations as indicated and the process evolves as already illustrated above. This procedure continues to loop until the snowfall event stops.
Goal	The goal is to avoid that (i) proactive treatments are performed in the wrong way and at the wrong moment, thus reducing the wastes of salt and road maintenance resources and (ii) snow removal operations are organized more wisely and efficiently, e.g. in order to reduce unnecessary repetitions of trips.
Actors	Road maintenance activities responsible, road operators.
Constraints	The efficiency of this use case may be suboptimal if (i) the MDSS is not sufficiently accurate and reliable, and does not offer a comprehensive assessment of the snowfall event. The main inconvenient situations may occur in case of uncertainty conditions, in which there is a non-negligible probability that the weather front will not touch the road network under control. Even in this case, localized treatments can be applied in a suboptimal way with respect to ideal ones suggested by the on-board system because of the practical limitations in properly following the received suggestions while en-route.
Inefficiencies addressed	INEF_5, (INEF_1, INEF_2 and INEF_7)
Exceptions	The decision-making process can be significantly influenced by possible issues

	concerning the responsibility of treatment actions. In fact, the managers who are overall responsible for the road maintenance activities in a certain sector of competence may overestimate and oversize the amount of operations which would be really needed for managing such a weather event, in order to avoid any possible risks in terms of road safety and thus minimize damages to people and goods. In this way, any litigation with road travelers could be avoided in advance.

Table 30: UC_3: Diurnal proactive snowfall treatments.

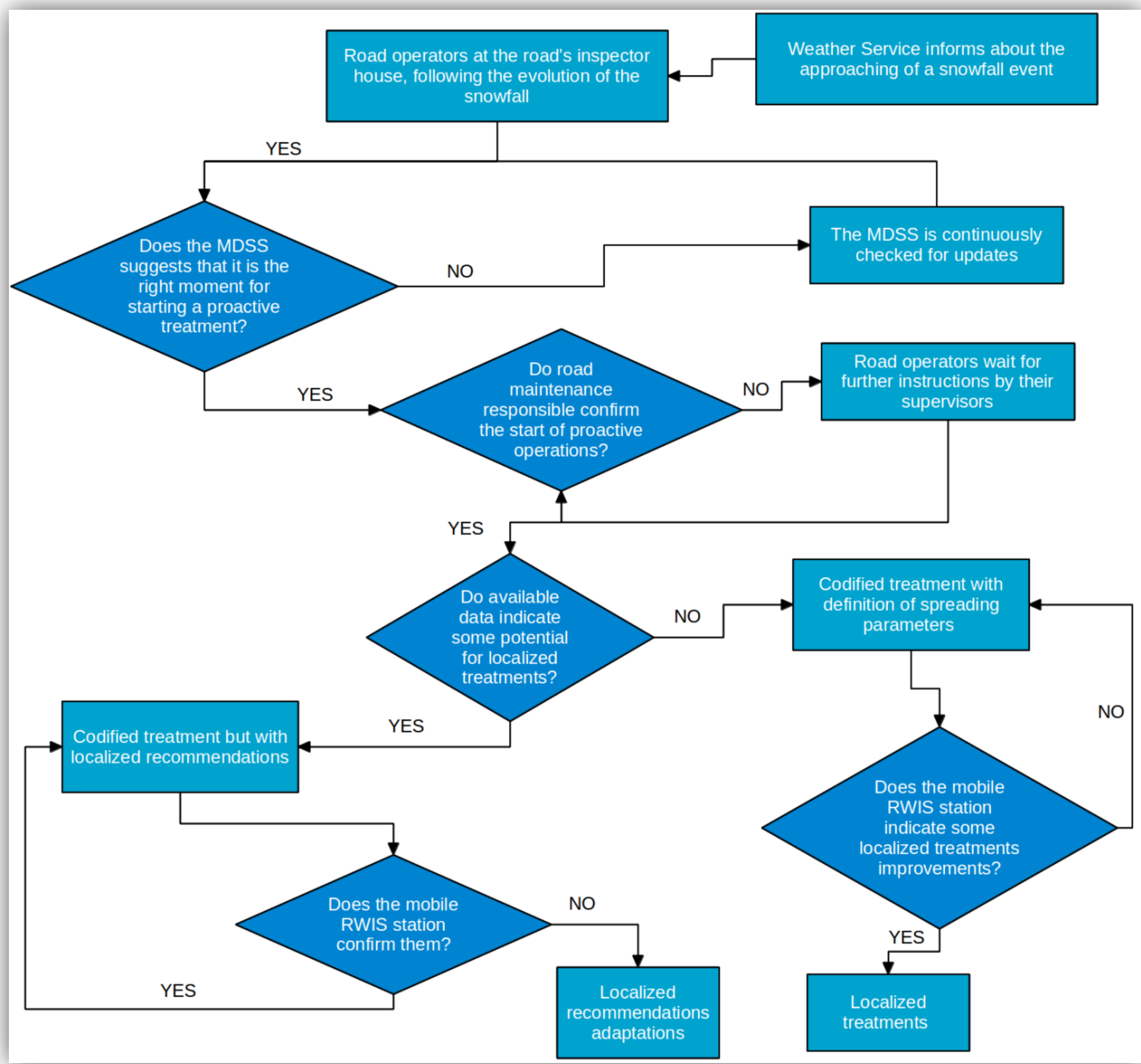

Figure 43: UC_3 main flow.

4.1.4 UC_4: Nocturnal proactive snowfalls treatments

While UC_3 deals with snowfalls events happening during the day, UC_4 evaluates what happens if they occur during the nocturnal phase, and in particular very near to the morning when most of local travelers use to move in order to reach their place of work or study. The main difference is in this case that this situation may surprise more the road operators and more in general all the road maintenance organization, and can potentially produce more

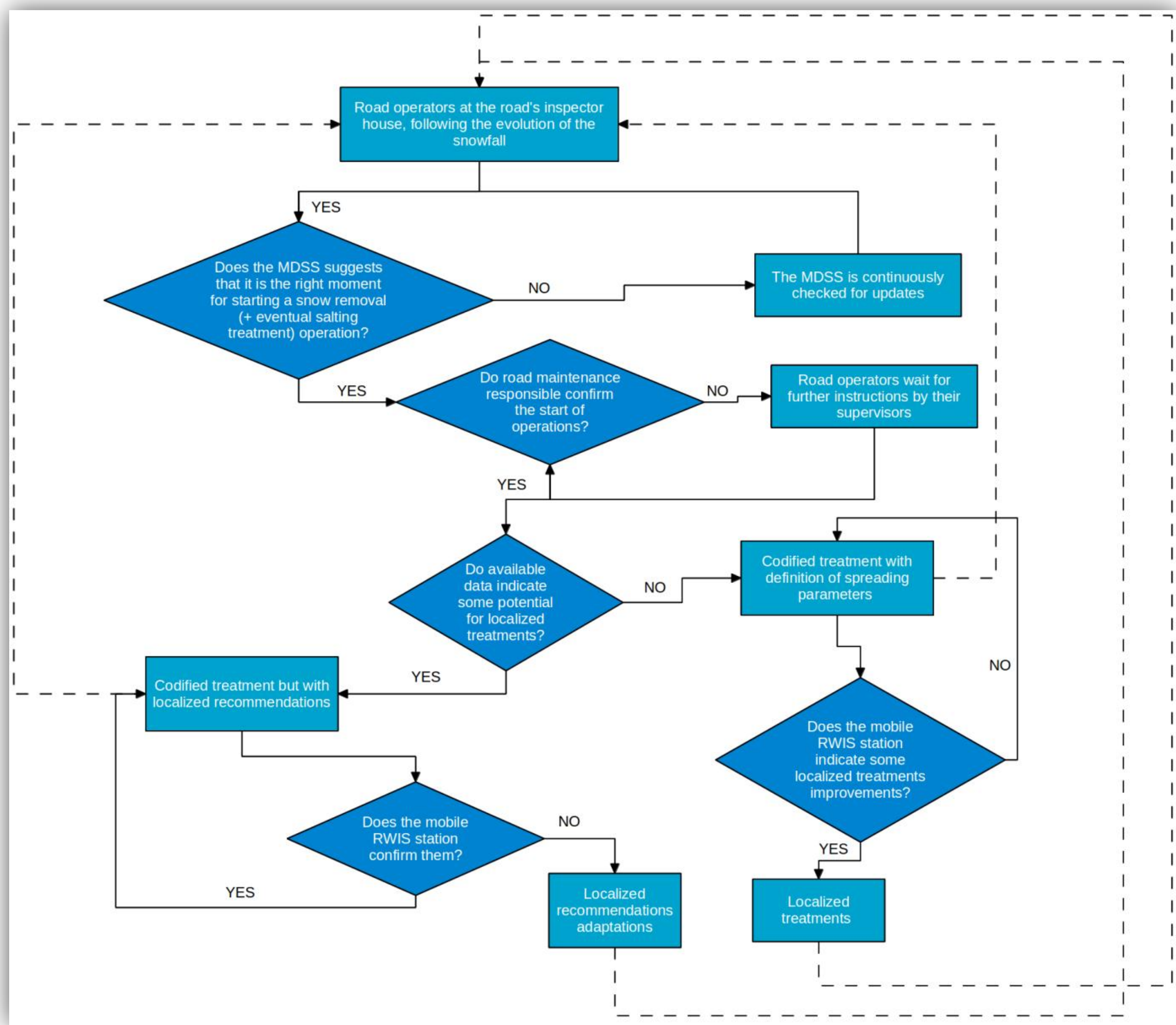

Figure 44: UC_3 and UC_4 following snow removal operations main flow.

disservices problems. It is worth noting that this use case may also take special days (e.g. non-working days) in which the road monitoring activities are ensured by the road operator in charge of the surveillance service. The details concerning this use case are described in Table 31, while the main flow is presented in Figure 45. Figure 44 presents the standardized snow removal operations that are in common with UC_3.

UC_4	Nocturnal proactive snowfall treatments
Reference use case scenario	The road operator in turn for the nocturnal surveillance service monitors the evolution of the snowfall event. Actually, his attention is triggered by the MDSS when certain thresholds situations have been reached. The attention of his chief and of all the other colleagues is triggered, and if case of need of the main responsibles of the road maintenance activities as well. The road operators' team meet immediately at the road inspector's house and the process already indicated in UC_3 can take place.
Goal	The goal is the same as in UC_3, and additionally to minimize the time in which the road operators' team enters in action in order to properly manage the weather event. The alert instruments which are proposed aim to minimize the stress and

	the anxiety of the road operator in turn for the nocturnal surveillance service.
Actors	Road maintenance activities responsible, road operators.
Constraints	The efficiency of this use case may be suboptimal if (i) the MDSS is not sufficiently accurate and reliable, and does not offer a comprehensive assessment of the snowfall event. The main inconvenient situations may occur in case of uncertainty conditions, in which there is a non-negligible probability that the weather front will not touch the road network under control. Even in this case, localized treatments can be applied in a suboptimal way with respect to ideal ones suggested by the on-board system because of the practical limitations in properly following the received suggestions while en-route.
Inefficiencies addressed	INEF_5, (INEF_1, INEF_2 and INEF_7)
Exceptions	The considerations made in UC_3 apply in this use case as well; moreover, the road operator in turn may anticipate the initial alerting operations if he does not trust too much the alerting capabilities of the MDSS and/or if he lives this risky situation without the proper self-control, thus reducing the potential impact of alleviating the stress and anxiety on nocturnal monitoring activities normally take place under these circumstances.

Table 31: UC_4: Nocturnal proactive snowfall treatments.

4.1.5 UC_5: Post-snowfalls treatments

Finally, UC_5 deals with the typical situation to treat the roads during the evening, i.e. before the nocturnal phase starts. This happens commonly after a snowfall event, since snow residuals on the road can facilitate the formation of ice and thus put in the danger the transit of vehicles at night. In this case, the optimization margin has been evaluated to be low for the case study under evaluation, since most of the actual post-snowfalls (or in general, the ones taking place during the evening) are considered to be necessary based on the actual road conditions. However, the introduction of a RWIS could inevitably increase the assessment of what's happening (and will happen in the near future) on the road surface and thus optimize the available salting, human and hardware resources. It is worth noting that while in the previous use cases, a very short nowcast prediction was implicitly required for properly supporting this decision-making process (e.g. 3-4 hours at maximum), in this case the MDSS should be able to predict the evolution of the road conditions ideally until the following morning, with a time horizon which could reach 12 hours – hence we don't speak of nowcast predictions any more but of out-and-out forecasts. This prediction could be however less accurate and bring to suboptimal or conservative decisions, thus further decreasing the potential improvement which may be achieved in these reference situations; in any case, the road operator in turn may be alerted during the nocturnal evolution of sudden changes in the meteorological conditions and thus properly activate de-icing operations (ref. UC_4). It is also possible that the leader of the road operator's decides for a patrol trip and to apply localized treatments based on both the data gathered by the mobile RWIS station as well by the perception of the individual road operator. The details of UC_5 are described in Table 32.

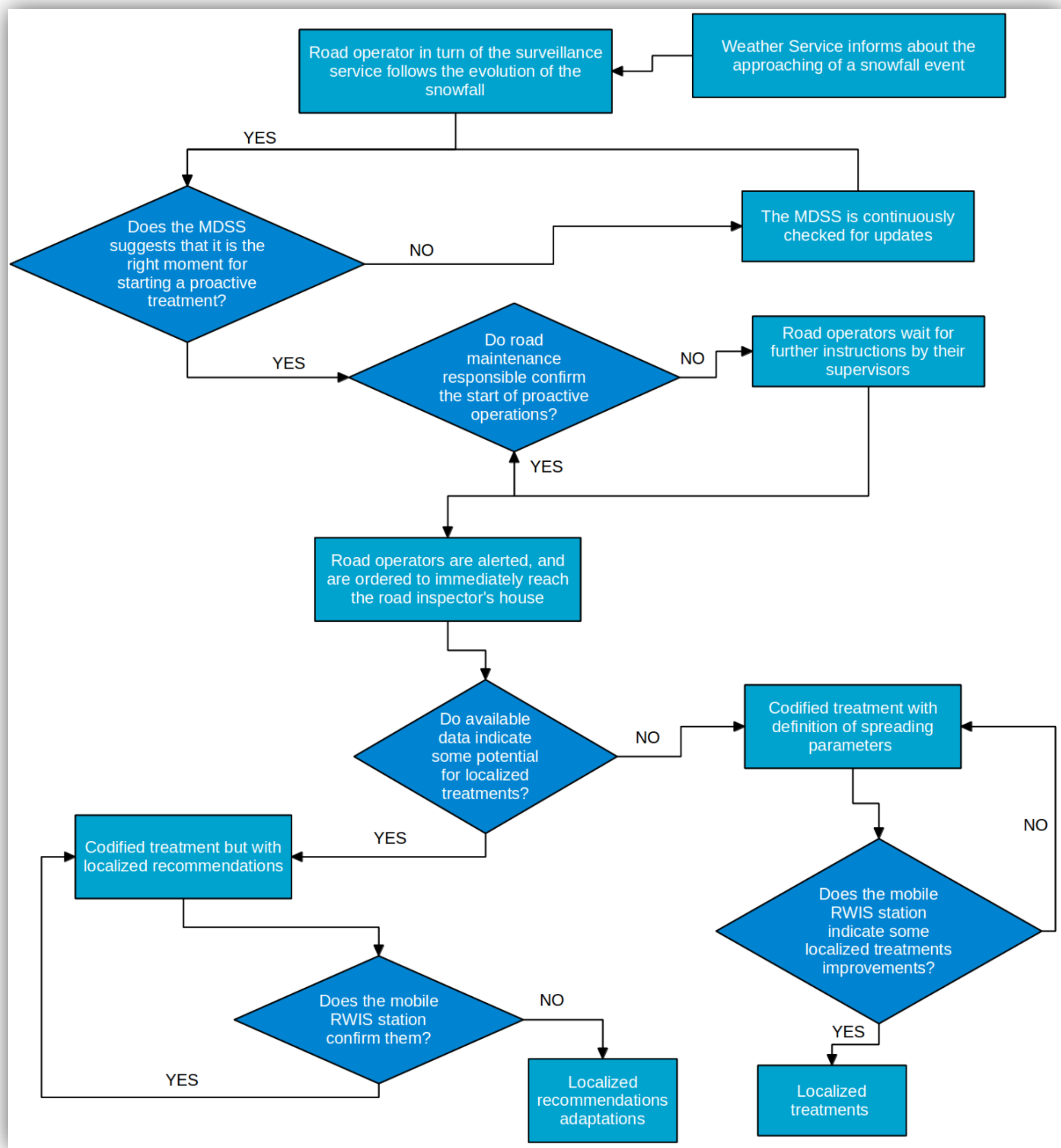

Figure 45: UC_4 main flow.

UC_5	Post-snowfall treatments
Reference use case scenario	The road operators' team is in the road inspector's house and evaluating together the outputs provided by the MDSS. It has been a hard work day because of the recent snowfalls and this is the last internal meeting before to go home, in which it has to be decided whether to carry out an evening de-icing treatment or not. Thanks to its additional forecast capabilities, the MDSS is able to provide a projection of how road conditions will evolve up to the following morning, when the successive road treatment may take place (ref. UC_2). The MDSS does not only show the outputs of the automatic model(s), but also offers the specific recommendations received by the Weather Service, which describe the expected

	progress of the meteorological conditions during the following night. The road operators may also check the data collected by the RWIS stations, in particular the static ones offer a perspective of the presence of a certain water film on the road as well as the actual road surface temperature; the mobile ones offer a consolidated overview of eventual cold points which may be treated specifically. The leader of the road operators' team takes his final decision about the necessity to apply a treatment or not, and if necessary in coordination with the responsible(s) of the road maintenance activities in the sector of competence, who have also a remote access to the MDSS and can thus properly monitor the actual situation. Road operators start their evening treatment and record their operations, collecting spatially distributed data through the mobile RWIS station. Even in this situation, localized treatments can be applied on the base of this latter information source, which indicate this dynamic adaptation through the on-board monitor.
Goal	The goal is to make sure that post-snowfall treatments are performed only when effectively necessary, and using the right amount of salt which is driven by the effective needs of the road.
Actors	Road maintenance activities responsible, road operators.
Constraints	The efficiency of this use case may be suboptimal because forecasts can be less accurate than nowcast predictions, and could be not in the condition to foresee sudden changes in the meteorological conditions during the nocturnal phase. This will lead to the necessity to call back in service the team (i.e. UC_4) and thus negative outcomes on the quality of the work they are able to produce. Additionally, as pointed out in the previous use cases, localized treatments (which under these conditions could be much more relevant) can be applied in a suboptimal way with respect to ideal ones suggested by the on-board system because of the practical limitations in properly following the received suggestions while en-route.
Inefficiencies addressed	INEF_6, (INEF_1, INEF_2 and INEF_7)
Exceptions	The responsibility issue could be the major factor that could push, in particular during conditions of uncertainty, decision-makers to decide for conservative evening treatments, despite of the potential optimization margins highlighted by the MDSS.

Table 32: UC_5: Post-snowfall treatments.

4.2 Travellers use cases

The empirical assessment of the inefficiencies addressing local travelers presented in the previous chapter has in particular pointed out the potential benefits of introducing at a local level enhanced *Advanced Traveler Information Services* (ATIS), which may generate positive impacts on the several inefficiencies which are observed on the road (weather-influenced traffic levels reductions, traffic congestion phenomena, dynamic speed choices, road safety).

4.2.1 Use cases assessment through public survey

In order to explicitly confirm this, and to understand how further would people go in having access to them, some additional questions have been included in the aforementioned public survey, already discussed in Chapter 2, namely:

- in the future there will be a plenty of advanced services available on different channels (smartphones, tablet, PCs, satellite navigator, etc.) informing you about current road conditions. How do you evaluate this future scenario?

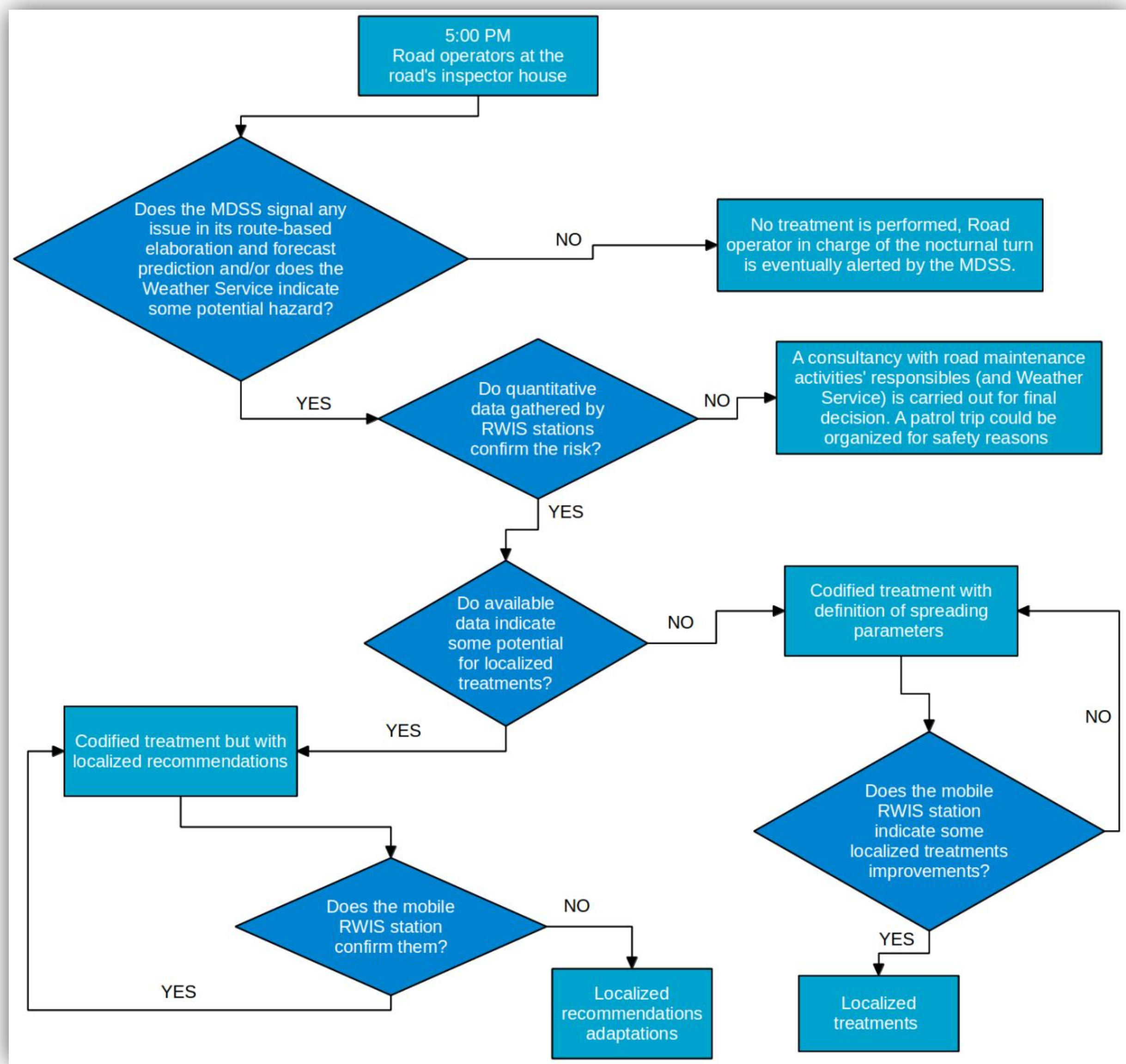

Figure 46: UC_5 main flow.

- how much would you pay in order to have more accurate information concerning weather events and road conditions forecast, as well as traffic conditions alerts?

The results to the first question (reported in Figure 47 and Table 33) demonstrate that a very high majority of local travelers would have at disposal these advanced services. It is interesting to observe that about half of them (42,4%) revealed to be fully in favor to get real-time information about the road conditions, since he could drive safer and eventually adapt his/her travel choices; the remaining ones (41,7%) have preferred to point out that this information is effectively useful if integrated with other more traditional traffic information services as well. The percentage of very skeptical users is about 14,3%.

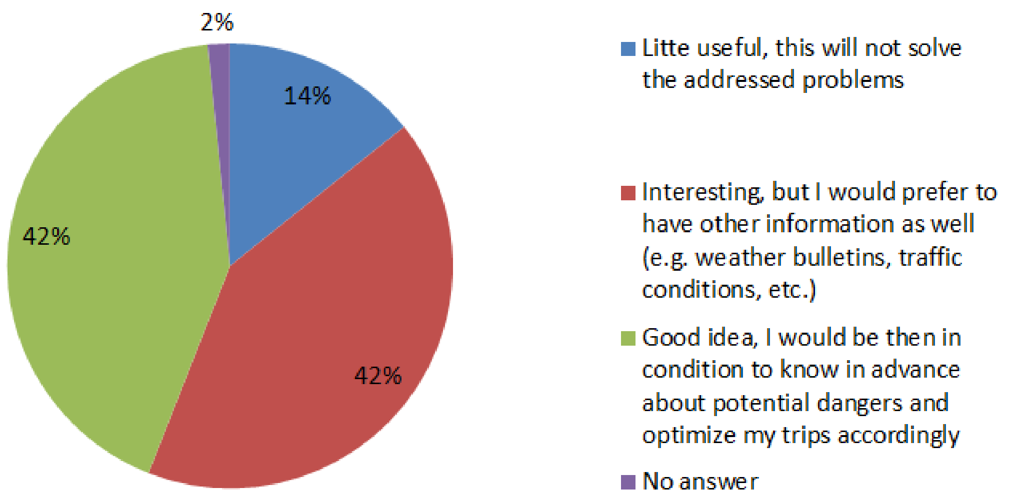

Figure 47: Public survey results – acceptance of future Advanced Traveler Information Services.

In the future there will be a plenty of advanced services available on different channels (smartphones, tablet, PCs, satellite navigator, etc.) informing you about current road conditions. How do you evaluate this future scenario	Values (nr.)	Values (%)
Little useful, this will not solve the addressed problems	178	14,3%
Interesting, but I would prefer to have other information as well (e.g. weather bulletins, traffic conditions, etc.)	521	41,7%
Good idea, I would be then in the condition to know in advance about potential dangers and optimize my trips accordingly	530	42,4%
No answer	20	1,6%

Table 33: Public survey results – acceptance of future Advanced Traveler Information Services (details on answers).

The answers related to the second question, presented in Figure 48 and in the tables below, are probably more interesting, since they immediately reveal the availability by local travelers to pay something in order to get these services. The results indicate the people are at most interested in paying for traffic events alerts services (61,7% have revealed to pay "sufficiently", "quite a lot" or "very much" for them), but also road weather information services have demonstrated to have at local level a non-negligible market potential, with a slight preference for the prediction of road conditions (51,2%) rather than precipitation events (39,5%).

How much would you pay for … precipitation events forecasts?	Values (nr.)	Values (%)
Very little	350	28,0%
Little	392	31,4%
Sufficiently	401	32,1%
Quite a lot	84	6,7%
Very much	9	0,7%
No answer	13	1,0%

Table 34: Public survey results – availability to pay for future Advanced Traveler Information Services (precipitation events forecasts).

How much would you pay for … road conditions forecasts?	Values (nr.)	Values (%)
Very little	253	20,3%
Little	342	27,4%
Sufficiently	433	34,7%
Quite a lot	184	14,7%
Very much	22	1,8%
No answer	15	1,2%

Table 35: Public survey results – availability to pay for future Advanced Traveler Information Services (road conditions forecasts).

How much would you pay for … traffic events alerts?	Values (nr.)	Values (%)
Very little	193	15,5%
Little	275	22,2%
Sufficiently	477	38,2%
Quite a lot	248	19,9%
Very much	45	3,6%
No answer	11	0,9%

Table 36: Public survey results – availability to pay for future Advanced Traveler Information Services (traffic events alerts).

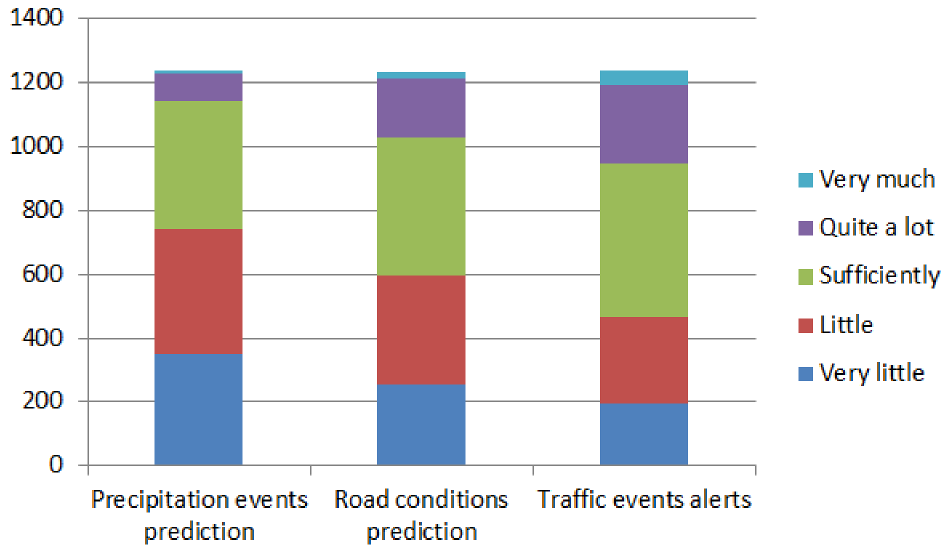

Figure 48: Public survey results – availability to pay for future Advanced Traveler Information Services.

Based on these results, three main use cases addressing local travelers' inefficiencies are considered (Table 37). It is worth noting that only one of the inefficiencies at background layer is specifically addressed here (i.e. INEF_13 "Traveler Information Services"); INEF_12 "Drivers education and equipment" is not going to be centrally considered in the CLEAN-ROADS system (even if it is indirectly targeted by one of the three proposed use cases), but will be the most relevant issue targeted by the dissemination activities of the CLEAN-ROADS project, which could be eventually supported through additional initiatives and policies activated by the local authorities.

ID	Title	Use Case Scenario	Reference inefficiencies
UC_6	**Road weather pre-trip information**	A local traveler is planning his/her commuting or occasional trip. He/she has heard that the meteorological conditions could be quite problematic in the short-term, so he/she decides to consult one of the on-line services in order to check the forecasts of precipitation events, road conditions and traffic levels within the local roads. Thanks to this information he/she may optimize his/her car trip (e.g. choice of the most appropriated vehicle, choice of the travel time, choice of the route, etc.) and/or eventually decide to take another transportation mean (even in multi-modal mode). In the latter case, he/she includes in his/her travel planning activities a detailed evaluation of public transportation information as well.	INEF_13, INEF_8, INEF_9, INEF_11
UC_7	**En-route road weather on-board information**	A driver is on board of his/her vehicle and carrying out his/her trip based on the plan defined in UC_6. Thanks to the on-board real-time travel information service, he discovers that a traffic jam has suddenly occurred along his/her planned route; the on-board navigator provides him some suggestions for routes alternative and he/she decides to take the most suitable one. The on-board service also alerts him/her that he/she is approaching a potential dangerous road stretch, which despite the recent road treatment has however just presented ice formation processes on the surface. The driver gets informed about the entity of the risk and receives recommendations about the maximum speed he/she should drive in order to minimize any possible safety risks.	INEF_13, INEF_9, INEF_10, INEF_11
UC_8	**En-route road weather information on Variable Message Signs**	The scenario is exactly the same as in UC_7, but in this case the information is not available on-board in a somehow personalized form but broadcasted through the available network of Variable Message Signs (VMSs). These may include both traffic and road weather events which should be suddenly communicated to all drivers in order to minimize the inefficiencies of the road. UC_8 can be directly connected with UC_7 in the sense after being informed about the available issues through the VMSs people on board of a vehicle may support the driver to know more about them through the on-board device. In this scenario, it could be also possible to foresee the introduction of *Variable Speed Limits* (VSL), which could be automatically set based on the current road surface conditions and communicated to the drivers to the VMSs. These new limits are not recommendations, but effective legal limits that drivers must respect: possible infractions could be eventually detected by available	INEF_12, INEF_13, INEF_9, INEF_10, INEF_11

	reinforcements systems and consequently punished.

Table 37: Local travelers use cases with matches to reference inefficiencies.

The details of each proposed use case are available in the following paragraphs. A joint flow chart including all potential different travel plan variations which may be decided both during the pre-trip phase as well as while en-route is finally presented in Figure 49.

4.2.2 UC_6: Road weather pre-trip information

UC_6	Road weather pre-trip information
Short description	The travelers can optimize their travel plan choice and the vehicle equipment based on the current road weather conditions, which are available on-line through different ATIS. Thanks to this, they are able to (i) avoid to use a not properly equipped vehicle; (ii) schedule their trips to avoid possible critical situations; and (iii) choose the most appropriate travel mean(s). In the latter case, public transportation information (possibly in real-time) are properly checked. By doing so travelers will be in the condition to limit the use of non-properly equipped private cars; (ii) increase the efficiency and the safety in how the road infrastructure is used; and (iii) reduce the overall environmental impact of their travels.
Goal	The overall goal is to maximize the efficiency of trip choices, such that (i) the traffic levels are maximized independently of the weather conditions (ref. INEF_8); (ii) the impacts of traffic disruptions are minimized (ref. INEF_9); and (iii) road travels can always take place in the highest safety conditions (ref. INEF_11)
Actors	Local travelers
Constraints	Real-time information about the road weather condition in the different areas of the Autonomous Province of Trento, especially in the case study route, must be available and accessible from the different on-line services.
Inefficiencies addressed	INEF_8, INEF_9, INEF_11 and INEF_13
Exceptions	In certain situations, travelers can have specific personal needs which are in conflict with the travel choices recommendations given at “central” level. In this cases, it could be possible that the traveler will need to take a suboptimal travel decision, even if properly aware about the possible road weather hazards.

Table 38: UC_6: Road weather pre-trip information.

4.2.3 UC_7: En-route road weather on-board information

UC_7	En-route road weather on-board information
Short description	The travelers’ information services available on top of the CLEAN-ROADS system can be also consulted during a car trip through on-board equipment (e.g. personal devices, satellite navigator, etc.). In particular, sudden traffic and weather events are notified to the driver, which may be filtered on top of different criteria (e.g. car’s position) . In case of personal devices, the advantage is that the travelers can continuously check the real-time conditions even after they have dropped from their vehicle, which may be particularly important in a multi-modal journey. The road weather information is published by different B2C services which are linked to the B2B standard interfaces put at disposal by the CLEAN-ROADS system.
Goal	The overall goal is to maximize the efficiency of trips while en-route, such that (i) the impacts of traffic disruptions are minimized (ref. INEF_9); and (iii) road travels can always take place in the highest safety conditions (ref. INEF_10 and INEF_11)
Actors	Local travelers
Constraints	Real-time information about the road weather condition in the different areas of the Autonomous Province of Trento, especially in the case study route, must be available and accessible from the different on-line services.
Inefficiencies	INEF_9, INEF_10, INEF_11 and INEF_13

addressed	
Exceptions	Not all travelers may be equipped with on-board devices connected to online services; as a consequence, only a subset of drivers can be reached through these channels.

Table 39: UC_7: En-route road weather on-board information.

4.2.4 UC_8: En-route road weather information on VMSs

UC_8	En-route road weather information on VMSs
Short description	Drivers will be in the condition to optimize their travels while en-route thanks to the information published by the VMS, which can be of two different types: (i) real-time alerts concerning sudden road weather events, typically in the form of pre-coded messages (e.g. risk of ice on the road surface, possible snowfall, etc.); (ii) real-time traffic regulation updates, e.g. variation in the speed limits which are automatically regulated as a function of the current road weather situation. In the case of (i), travelers have the possibility to get practical indications in order to avoid any safety issue which may occur on the route to their destinations. In this scenario, VMSs could also integrate exceptional messages provided in case an exceptional road weather event (e.g. an intense snowfall) is approaching as a consequence of the actuation of a contingent action plan. In the case of (ii), drivers are in the condition to efficiently adapt their speed on the base of the current road conditions, and thus maximize the safety and comfort of their trip by respecting the suggested contingent speed limit.
Goal	The overall goal is to maximize the safety of vehicular trips, and induce drivers to follow a more appropriate driving behavior during the winter season.
Actors	Local travelers, local traffic officers
Constraints	The exploitation of similar scenarios are limited by the network of VMSs, which is expensive to maintain and increase. VSL strategies could be applicable only in some areas of the regional road network, where the number of installations is deemed sufficient.
Inefficiencies addressed	INEF_9, INEF_10, INEF_11, INEF_12 and INEF_13
Exceptions	Specific individual needs can be conflicting with respect to the messages available on the VMSs.

Table 40: UC_8: En-route road weather information on VMSs.

4.3 A glance to future cooperative scenarios

The technological analysis presented in D.A2.2 [1] has revealed the imminent diffusion in the market of cooperative ITS systems (C-ITS), based on new enabling communications technologies (i.e. vehicle-to-vehicle and vehicle-to-infrastructure, indicated with the acronyms V2V and V2I). Some international research projects, in particular in the USA and in Finland, are already exploring the potential and the feasibility of connected applications in the road weather domain. As a matter of example of the direction towards which the proposed CLEAN-ROADS system may evolve, the inputs coming from the research project WiSafeCar project have been considered there [11]. The reference scenario will be a fully-connected environment where vehicles will be in the condition to exchange real-time information with actors moving within their spatial horizon (e.g. nearby vehicles and roadside units, for example static RWIS stations) and actors working in the back-end (e.g. traffic management centers), as illustrated in Figure 50.

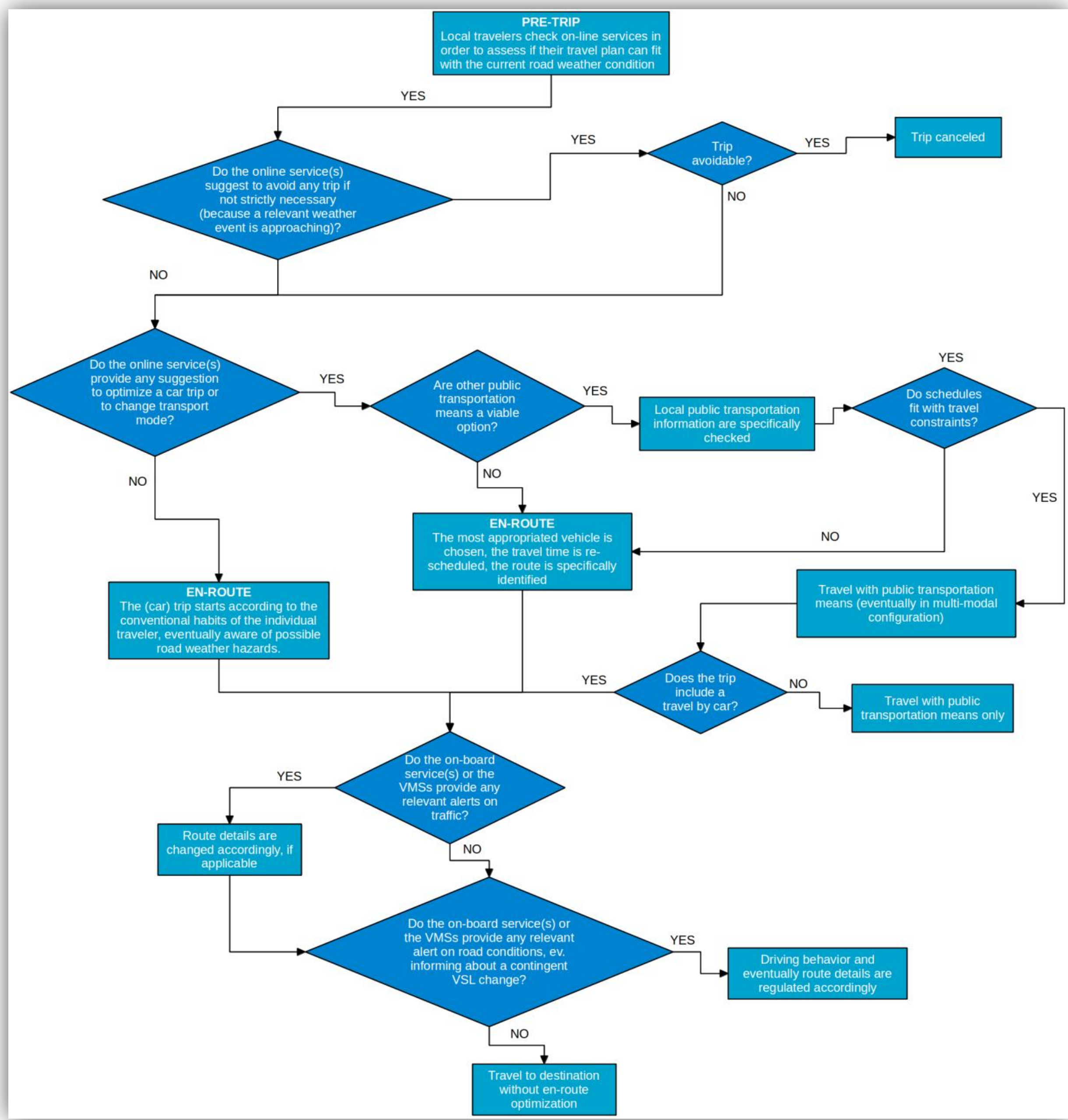

Figure 49: Local travelers' use cases joint main flow.

A possible list of future cooperative scenarios is furthermore presented in Figure 51. The added-value services here are mainly destined to **local travelers**, but actually **road operators** could benefit as well from this enhanced connected environment: e.g., their maintenance vehicle could automatically spread the optimal amount of salt along the route of interest based on the dynamic recommendations and inputs coming from the surrounding environment. The proposed use cases, as well as the CLEAN-ROADS reference system concept (to be presented in the following Chapter), have already in mind these future perspective of the road transport domain, and will be implemented in a way to minimize the effort which will be required to enhance this exploitation opportunity.

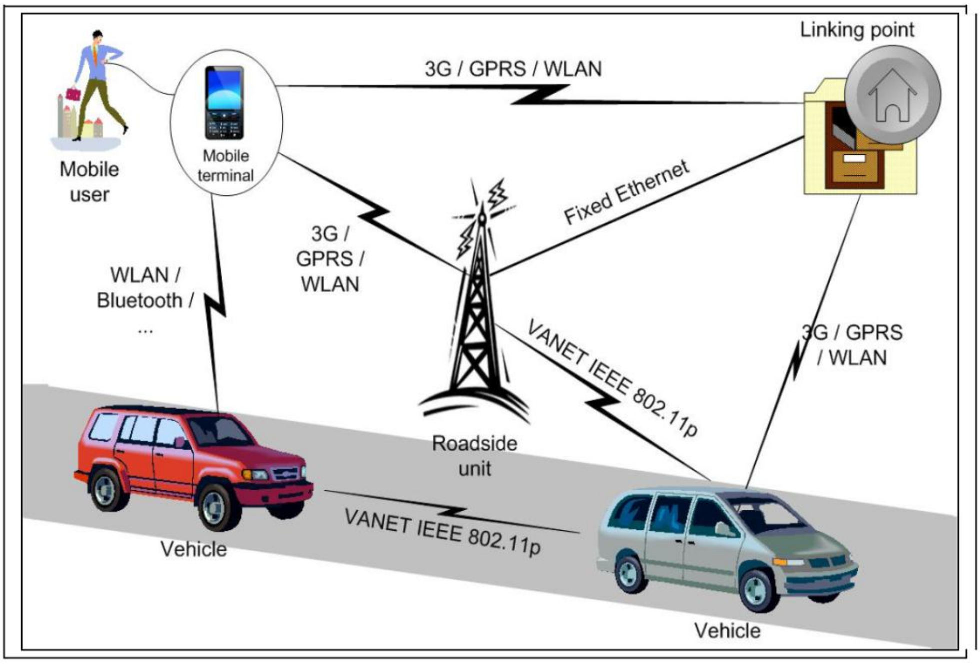

Figure 50: The system architecture of the WiSafeCar system [11].

Service	Overview	Internal Data Sources		External Data Sources (via Linking Point)
		Vehicle	Roadside Unit	
Accident warning	Accident in road interpreted	Airbag burst, GPS, emergency lights on	-	Accident info from authorities
Incident warning (BCW)	Exceptionally bad weather conditions interpreted or observed	Temperature, GPS	Road surface condition sensors, temperature, rain intensity, humidity, wind	Weather radars, weather stations etc., authorities
Incident warning (SRW)	Slippery road conditions observed in specific spot	Road surface condition sensors, gyroscope, GPS	Road surface condition sensors, temperature, rain intensity, humidity, wind	Weather radars, weather stations etc., authorities
Incident warning (AOV)	Indication of approaching emergency vehicle	Vehicle-to-vehicle information through VANET	-	-
Incident warning (RWW)	Indication of roadwork ahead	-	Infrastructure-to-vehicle information through VANET	-
Local road weather (RWS)	Local weather information and forecast to the location of vehicle	Temperature, road surface condition sensors, GPS	Road surface condition sensors, temperature, rain intensity, humidity, wind	Weather radars, weather stations etc.
Route weather	Weather information and forecast to the vehicle route options	Temperature, road surface condition, GPS	Road surface condition sensors, temperature, rain intensity, humidity, wind	Weather radars, weather stations etc.

Figure 51: The pilot services studied in the WiSafeCar project [11].

5. System concept

This chapter introduces the functional concept of the CLEAN-ROADS system, which is defined in order to efficiently match together (i) the expectations of local stakeholders and needs; (ii) the targeted inefficiencies; and (iii) the reference use cases. A fourth factor which is considered in this work of analysis is the evaluation of the international state-of-art, which is a fundamental aspect in order to let the system architecture be compliant with other architectures which are proposed in order to address similar challenges. The results of this preliminary technological assessment are presented in deliverable D.A2.2 “*Technological instruments and constraints*” [1].

The overall system concept of the CLEAN-ROADS is illustrated in Figure 52. A heterogeneus set of data sources (fixed / mobile, field measurements / output models) feed a central elaboration system, in which road conditions are computed and forecasted. This information is available at different levels of details and based on different user privileges / reference use cases (i.e. involving road maintenance responsibles and operators, or local travellers) through a comprehensive multi-channel informative system, which is composed on one side by the *Maintenance Decision Support System* (MDSS) and on the other side by the *Advanced Traveller Information System* (ATIS) platform.

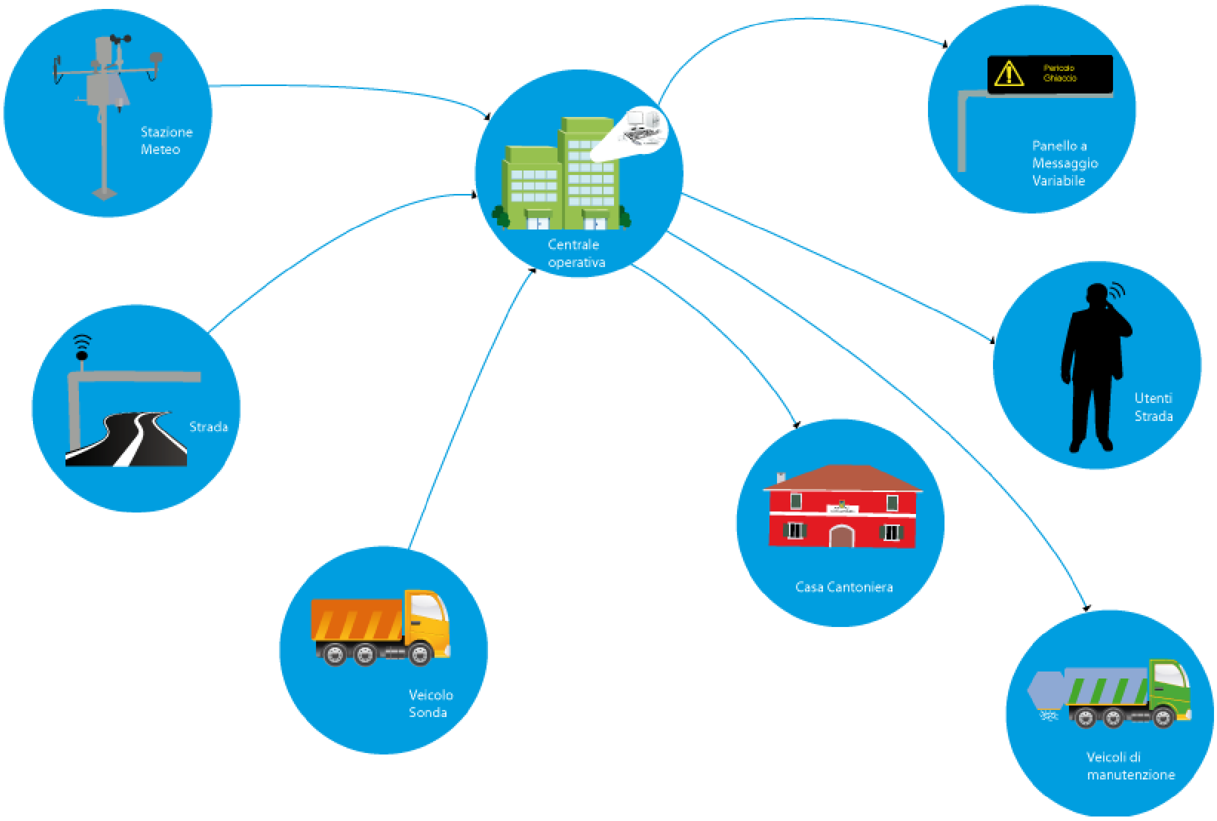

Figure 52: The high-level concept of CLEAN-ROADS.

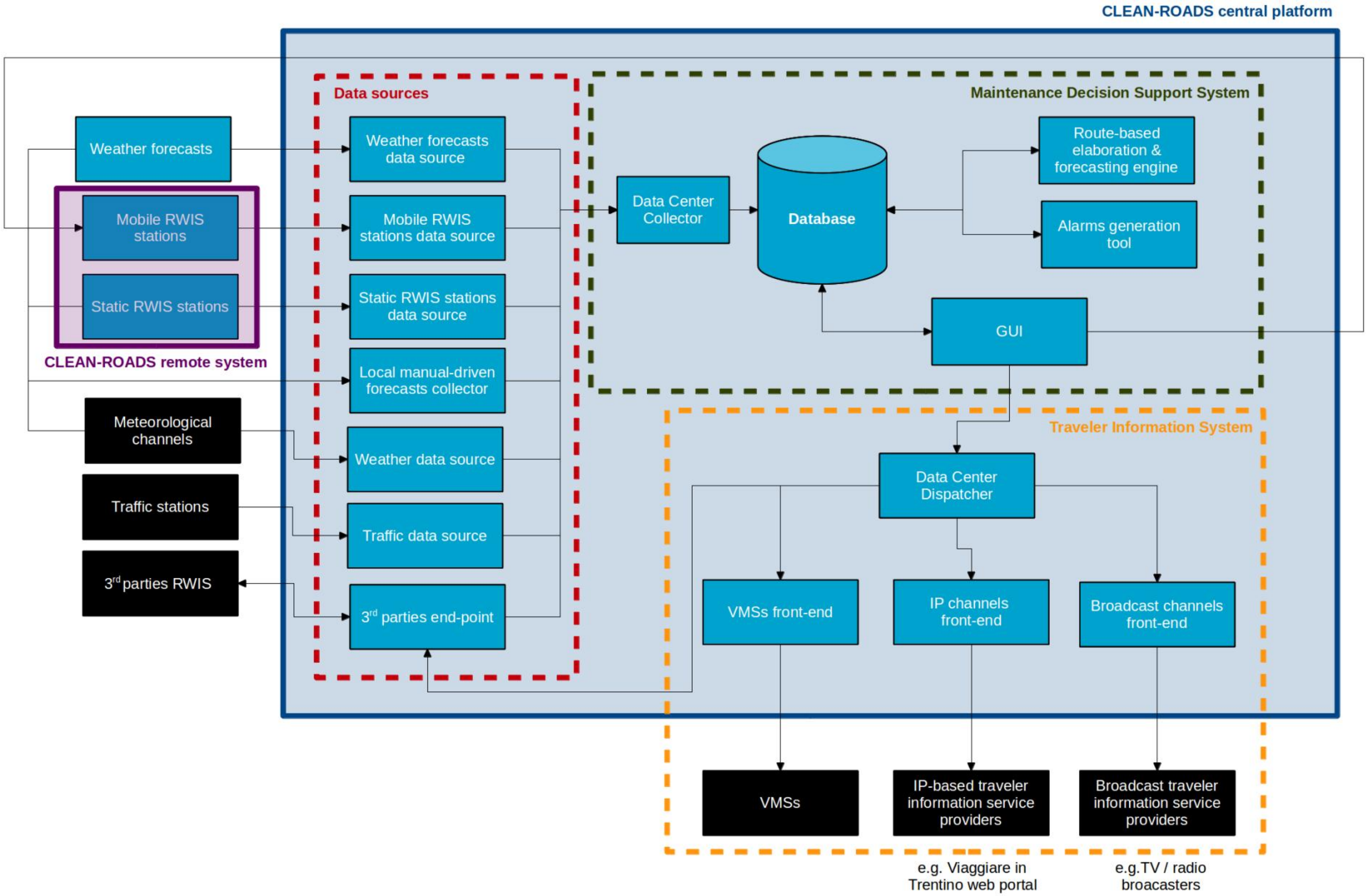

Figure 53: The functional architecture of CLEAN-ROADS system.

A detailed schema of the functional architecture of the CLEAN-ROADS system is illustrated in Figure 53, in which the four main system components are highlighted: (i) the **CLEAN-ROADS remote system**, which is responsible for the field monitoring as well as road maintenance operations; (ii) the **data sources subsystem**, in which all input data are gathered and pre-validated; (iii) the **MDSS**, which stores all the validated data, process it in order to generate a real-time and forecasted picture of the road conditions, eventually generates in automatic mode a series of alarms and presents this raw and elaborated information thrugh a road operator GUI; and (iv) the **ATIS**, in which relevant travel information, eventually manually altered by human interventions, is shared to a heterogeneous population of travel information services in a B2B approach (very similarly as what was proposed in the LIFE+10 ENV/IT/389 INTEGREEN project [12]). The latter three components form together the overall **CLEAN-ROADS central** (software) **platform**. The schema does not only highlight the components of the CLEAN-ROADS system (in blue colour), but also those ones which are outside of it (in black) but are somehow directly connected to it.

A detailed description of the single system components is briefly offered in the next paragraphs. Chapter 6 will finally characterize each of them in terms of functional and non-functional requirements. <u>It is worth noting that the present architecture represent just a reference high-level complete vision for the design and implementation activities of CLEAN-ROADS; so, the implementation of some of the system components (e.g. the 3rd parties end-point) will be specifically checked based also on the effective availability of external sources</u>.

5.1 Remote system and data sources

The data sources subsystem is the point of the entire CLEAN-ROADS architecture in charge of providing a consistent API for the retrieval of well-defined class of raw data from sources which can be inside or outside the boundary of the system over a variety of supported protocols at different layers of the ISO/OSI reference stack. More specifically, seven specialized data sources, responsible for the proper reception and pre-validation of certain data sets as well as the aggregation and forwarding operations, have been defined, namely:

- the weather forecasts data source;
- the mobile RWIS stations data source;
- the static RWIS stations data source;
- the local manually-driven forecasts collector;
- the weather data source;
- the traffic data source;
- the 3rd parties end-point.

5.1.1 Weather forecasts data source

This data source is specialized in the retrieval of weather forecasts, which will be used together with other data inputs in the MDSS in order to generate the route-based elaboration and forecast outputs. More specifically, this data source handles the output data of several weather forecasts model in use by the Weather Service of the Autonomous Province of Trento (e.g. ECMWF, COSMO N2 RUC and WRF).

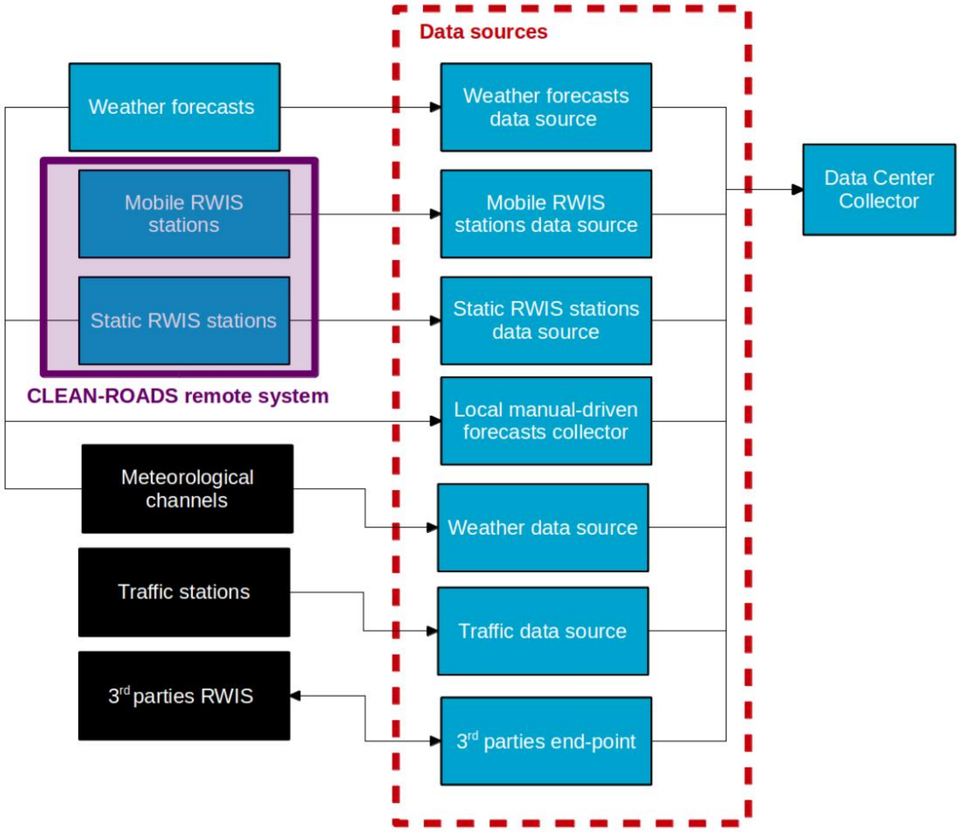

Figure 54: The functional architecture of the remote system and data sources layer of CLEAN-ROADS.

5.1.2 Mobile RWIS stations subsystem

This subsystem is made up of the fleet of mobile RWIS stations (which be installed on the maintenance vehicles at disposal of the Road Maintenance Service of the Autonomous Province of Trento) and its reference data source. The mobile RWIS stations have a dual monitoring task, i.e. to collect and forward (i) geo-referenced data gathered from a variety of **on- board sensors** (not excluding the possibility of a direct connection to the CAN bus of the vehicles), e.g. for thermal mapping operations and (ii) geo-referenced **information about the maintenance activities** that the road operators are carrying out. A third functionality is the possibility to offer to the road operator through a proper portable device (e.g. a tablet) relevant **real-time information** that can let him to "dynamically" improve his maintenance tasks. The data collected by the RWIS mobile probe is going to be mainly used to **post-calibrate and enrich the spatial predictions computed within the MDSS**, e.g. to detect very localized hazards or to confirm the alarms generated by the road weather model(s).

5.1.3 Static RWIS stations subsystem

This subsystem is made up of the network of static RWIS stations installed during the first project phase and its reference data source. Static RWIS stations can be seen as "enhanced meteorological stations” that are not only installed at specific locations (i.e. at the road side), but also in condition to collect a plenty of additional data that can be useful for the road conditions predictions, i.e.:

- **meteorological** data;
- **road surface** condition;
- **traffic** data;
- other useful data, e.g. for **environmental monitoring** purposes.

5.1.4 Manual forecasts collector

Weather data and forecasts are quite difficult to aggregate and interpret; for this reason, there is a need of pool of expert meteorologists that know well the mountainous territory under study, can efficiently aggregate the different automatic inputs coming from the different weather channel and produce very precise weather bulletins for the local population. In the CLEAN-ROADS system, the Weather Service of the Autonomous Province of Trento will produce additionally **specific bulletins for the road maintenance staff**, in order to give them a supervised overview of the potential risks that may occur on the roads because of the appearance of meteorological phenomena. This collector will automatically receive these special bulletins (which will be produced at a specific temporal frequency, e.g. once/twice a day), check if they are properly formatted (based on standard conventions) and give them in input to the MDSS.

5.1.5 Weather data source

An useful input that can represent an added value for the road maintenance staff is the possibility to directly visualize in the MDSS the variety of meteorological data that are locally at disposal, e.g.:

- **meteorological monitoring stations networks** (e.g. the ones managed by of the Weather Service of the Autonomous Province of Trento or the one controlled by the Edmund Mach Foundation);
- **weather information** provided by on-line portals of **neighboring regions**;
- **radar / satellite images**;
- **web-cams** distributed in the region.

5.1.6 Traffic data source

The user needs analysis has put in clear evidence the necessity to create road monitoring tools which are deeply integrated with the traffic monitoring system. For this reason, in order to immediately check the impact that the current meteorological conditions are having on traffic, an additional, specific data source has been integrated in the CLEAN-ROADS architecture. Even in this case, the added value of this component is the possibility to create dedicated views in the GUI of the MDSS for the visualization of traffic data coming from static traffic detection stations, e.g.:

- **quantitative traffic levels data** (e.g. vehicles number, vehicles classification, speed profiles, etc.);
- **qualitative traffic monitoring** (e.g. images / videos acquired from traffic cameras or webcams).

5.1.7 3rd parties end-point

The 3rd parties information data source is an optional component that can be added to the CLEAN-ROADS system if interfaces with other local RWIS are available (e.g. A22 highway, Province of Bolzano, etc.). This data source would represent a further instrument, in particular for the road maintenance staff, for extending the spatial monitoring capabilities of the CLEAN-ROADS monitoring system, and would put it in the condition to better predict and react to some critical situations. For example, it could be useful to know exactly how a snowfall event is moving and approaching the regional road network, and if any traffic events have appeared because of these weather conditions. Obviously, the benefit is reciprocal, since other RWIS systems could benefit from the output information generated by the CLEAN-ROADS systems and put at their disposal through this end-point.

5.2 Maintenance Decision Support System

The Maintenance Decision Support System (MDSS) is the core subsytem of CLEAN-ROADS in which input data are centrally aggregated and stored, processed and presented to the road maintenance staff through a GUI (Figure 55).

The MDSS is characterized by four different components:

- the **Data Center Collector** (DCC), which represents a unique collection point of all input data coming from the different data sources. It is a unique, virtual entity that has the direct access to the tables of the database and has been mainly introduced for security and scalability reasons;
- the **database**, in which all raw data and generated outputs (e.g. route-based forecasts, alarms) are properly stored;
- the **route-based elaboration & forecasting engine**, which is a multi-dimensional road weather model able to compute route-based elaborations and forecasts of the route conditions primarily based on the CLEAN-ROADS remote system and the available weather forecasts;
- the **alarms generation tool**, which will automatically analyze the available data and forecasts and trigger alarms in case of need;
- the **GUI**, in which all relevant raw data and elaborated information are properly graphically presented to the road maintenance staff. This component gives the possibility to this specific user category to efficiently interact with the available data sets, e.g. in particular in the perspective of validation of pre-codified messages or manual introduction of special messages to the local travelers.

It is worth noting that the **return channel of the mobile RWIS station**, which is directly connected with the GUI in order to receive the on-board information for the optimization of the maintenance activities.

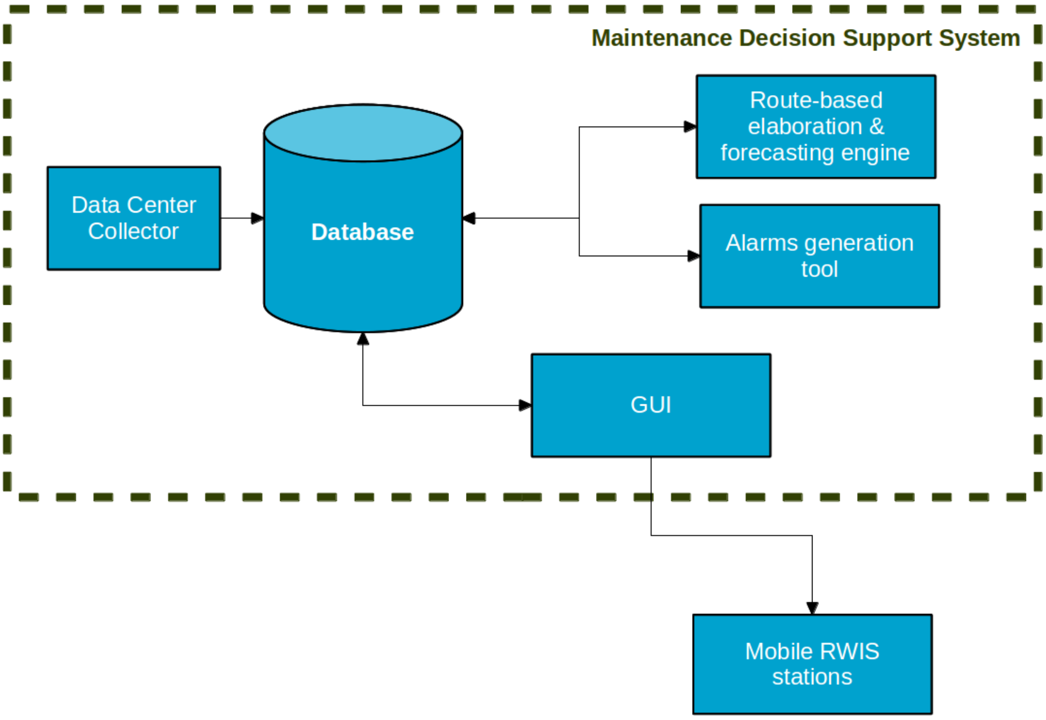

Figure 55: The functional architecture of the MDSS of CLEAN-ROADS.

5.3 Advanced Traveller Information System

The GUI of the MDSS will also have the capability to share a subset of relevant road / weather / traffic information to the ATIS subsystem (Figure 56). As mentioned before, the reference architecture follows a B2B approach with the idea to put at disposal the available data / information set through a variety of standardized web interfaces that can be accessed by different traveller information services providers in order to improve existing advanced real-time travel information (RTTI) applications (or generate new ones) to the local populations. The main components of the ATIS are the following:

- the **Data Center Dispatcher** (DCC), which represents the unique point of connection with the MDSS, similarly as what proposed with the DCD in the MDSS;
- the **VMSs front-end**, which has the specific role to deliver the human-controlled messages to the network of VMSs;
- the **IP channels front-end**, which is in charge to publish the output information that are destined to web-based RTTI applications;
- the **broadcast channels front-end**, which is in charge to publish the output information that are destined to broadcast RTTI applications (that typically transmit only a small subset of the available information because of technical limitations in the transmission channels and end devices).

The ATIS is connected to the 3rd parties end-point as well for the publication of relevant road weather data to other RWIS.

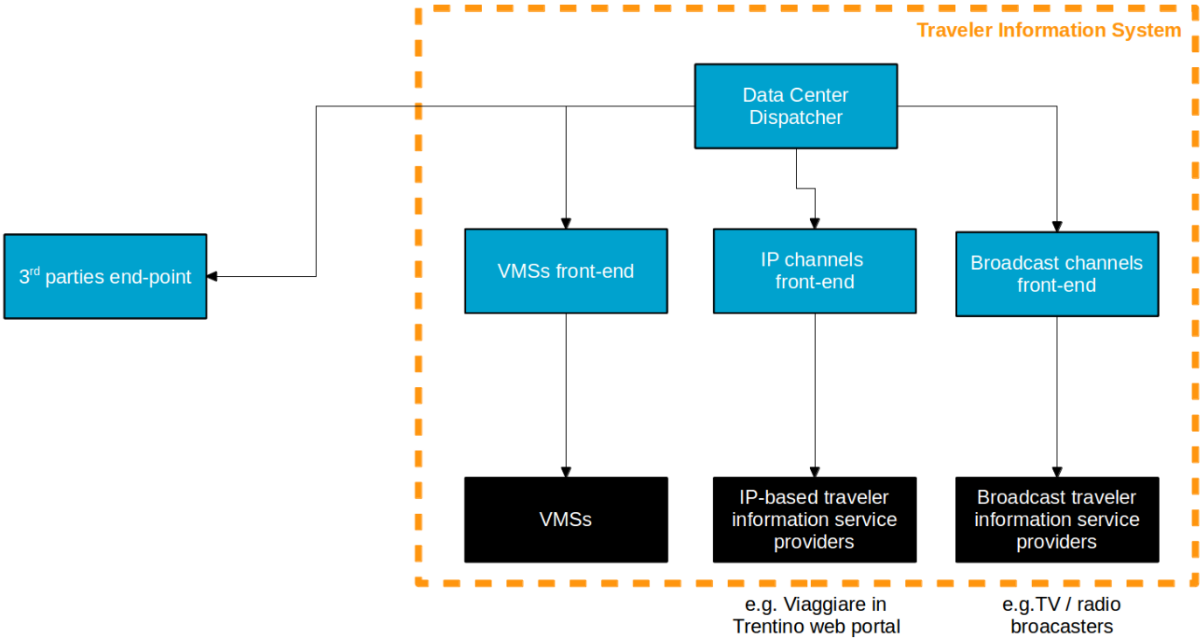

Figure 56: The functional architecture of the ATIS of CLEAN-ROADS.

6. Requirements

The main goal of this chapter is to finally consolidate the reference system requirements of the CLEAN-ROADS system described in the previous chapter. All the requirements are basically divided in:

- **functional requirements**, which define what the system is supposed ti do, and capture a specific function the system should provide;
- **non-functional requirements**, which defines how the system is supposed to be. These requirements are qualities related to functions such as performance, scalability, accessibility, extensibility, maintenance and so on.

The requirements description will follow the structure of Table 41.

	Title (understandable name)
ID	[component acronym] _ [numeric identifier]
Description	Short description containing the intention of the requirement
Rationale	Justify the requirements presence
Type	Functional / non-functional
Priority	**M** (must) / **S** (should) / **C** (could) / **W** (won't have)

Table 41: Reference requirements' template.

The *title* field contains a human understandable name that identifies the requirement; the *ID* field is on the contrary an identification code that allows to uniquely identify the specific requirement. The alphabetic part of the ID field is an acronym of the involved component while the numeric part is the actual progressive number of the requirement which is specifically associated to it. The *description* field provides a textual description of what the requirement is supposed to satisfy, even if it does not say anything about it can be technically satisfied. In addition to it, the *rationale* field explains in a synthetic way the reason why such requirement is needed. The *type* field indicates wheter the belongs to the aforementioned functional / not-functional categories, and in the latter case puts in evidence if it is eventually:

- an **interface** requirement, in order to highlight the presence of an interaction between components, modules, or other system parties;
- a **performance** requirement, which highlights the presence of reference quantitative constraints.

Finally, the *priority* indicates the level of priority of the requirement following the MoSCow prioritisation technique [13]. More specifically, four different prioritization levels are defined:

- **M – Must have**: critical requirements, which have to be included in the system in order to consider the project implementation completely successful;
- **S – Should have**: important requirements but less critical for the overall project implementation success;

- **C – Could have**: potential requirements that can increase customer satisfaction for little cost but that are not critical at all for the project implementation success;
- **W – Won't have**: these requirements are not going to be implemented in the project schedule, but they may be taken into account for further development activities.

The requirements are presented in distinct section, one for each component presented in the previous chapter. Each section is introduced by a list of common requirements that are shared by all the eventual sub-component belonging to the same components' class. In case of overlapping requirements between the component's class and a specific component, a reference role based on an hierarchical criterion is applied, i.e. the requirement which is defined at the most specific (e.g. the single sub-component) level takes the precedence over the others (e.g. the reference component or the system as a whole).

6.1 Definitions

In order to properly understand the contents of each single requirement, a set of specific definitions is introduced.

- **window observation**: a time interval which is needed from an arbitrary source to obtain as output a raw data which is representative for the observed phenomena in the reference temporal period;
- **monitoring instant**: refers to the ending instant of a window observation;
- **generated data**: the output produced by an arbitrary source at the end of a window observation, i.e. that is ready at the monitoring instant;
- **generated information**: the processed information which is the output of one of the elaboration chains of the system;
- **elaboration time interval**: the time interval which is needed to integrate the generated data in the overall, central elaboration chain and to possibly update the generated information;
- **timestamp**: is a sequence of characters or encoded information identifying when a certain event occurred, usually giving date and time of day, on top of a well-defined and commonly agreed standard.

6.2 List of requirements

A complete list of the requirements of the entire system is listed in Table 42.

Component	ID	Name	Type	Priority
Overall system	System capability	SC_1	F	M
	“Open data” approach	SC_2	NF(I)	M
	Internal interoperability	SC_3	NF(I)	M
	Output delay	SC_4	NF(P)	M
Static RWIS station	Data type	SRS_1	F	M
	Data type (optional)	SRS_2	F	S
	Data type – weather data	SRS_3	F	M
	Data type – weather data (optional)	SRS_4	F	S

Component	ID	Name	Type	Priority
	Data type – road surface conditions data	SRS_5	F	M
	Data type – road surface conditions data (optional)	SRS_6	F	S
	Data type – traffic	SRS_7	F	S
	Data type – environment	SRS_8	F	S
	Processing, transmission and other remote capabilities	SRS_9	NF	M
Mobile RWIS station	Basic data collection and information presentation functionalities	MRS_1	F	M
	Data type (optional)	MRS_2	F	S
	Data type – position and timestamp	MRS_3	F	M
	Data type – maintenance activities	MRS_4	F	M
	Data type – maintenance activities (optional)	MRS_5	F	S
	Data type – CAN bus data	MRS_6	F	S
	Processing, transmission and other remote capabilities	MRS_7	NF	M
Data sources	Data gathering	DS_1	F	M
	Data source isolation	DS_2	F	M
	Data packets validation	DS_3	F	M
	Data source forwarding service	DS_4	F	M
	Source position	DS_5	F	M
	Source status information	DS_6	F	S
	Warning capabilities	DS_7	F	S
	Source trustworthiness	DS_8	NF	M
	Authentication capability	DS_9	NF	M
	Data timestamp	DS_10	NF	M
	Source identification	DS_11	NF	M
	Source interoperability	DS_11	NF(I)	M
	Elaboration time	DS_12	NF(P)	M
Weather forecasts data source	Data type	WFDS_1	F	M
	Data type (optional)	WFDS_2	F	S
	Data format	WFDS_3	NF	M
	Data frequency update	WFDS_4	NF(P)	M
Static RWIS station data-source	Data frequency update – mandatory data types	SRSDS_1	NF(P)	M
	Data frequency update – optional data types (traffic)	SRSDS_2	NF(P)	S
	Data frequency update – optional data types (environment)	SRSDS_3	NF(P)	S
Mobile RWIS station data-source	Data frequency update	MRSDS_1	NF(P)	M
	Road weather and maintenance activities data packets independency	MRSDS_2	NF	S
Local manual-driven forecasts collector	Data type	MDFC_1	F	M
	Data frequency update	MDFC _4	NF(P)	M
Weather data source	Data type	WDS_1	F	M
	Provider and weather stations identification	WDS_2	NF	M
	Data frequency update	WFD_3	NF(P)	M
Traffic data source	Data type	TDS_1	F	M
	Data type (web cams)	TDS_2	F	M
	Data type (optional)	TDS_3	F	S
3rd parties end-point	Information type	3PEP_1	F	M

Component	ID	Name	Type	Priority
MDSS	Standard format	3PEP_2	NF	M
	Data exchange frequency update	3PEP_3	NF	M
	Client authentication and authorization	3PEP_4	NF	M
	MDSS capabilities	MDSS_1	F	M
	MDSS security	MDSS_2	NF	M
	MDSS performance	MDSS_3	NF(P)	M
	Flexibility and scalability	MDSS_4	NF(P)	M
Data Center Collector	Uniqueness	DCC_1	F	M
	Source and data source identification	DCC_2	F	M
	Database connection	DCC_3	F	M
	Authentication and security	DCC_4	NF	M
	Data sources authentication management	DCC_5	NF	M
	Multiple connections support	DCC_6	NF	M
Database	GIS capability	DB_1	F	M
	Generated data storing capability	DB_2	F	M
	Elaboration outputs and alarms storing capability	DB_3	F	M
	History and export capability	DB_4	F	M
	Logging, reports and warning management	DB_5	F	S
	Data incorruptibility & security	DB_6	NF	M
	Interfaces	DB_7	NF(I)	M
	Performance	DB_8	NF(P)	M
Route-based elaboration & forecasting engine	Road surface conditions – actual situation assessment	REFE_1	F	M
	Road surface conditions – forecasted situation assessment	REFE_2	F	M
	Elaboration outputs formats	REFE_3	NF	M
	Spatial resolution	REFE_4	NF(P)	M
Alarms generation tool	Calibration and malfunctioning problems discovery	AGT_1	F	M
	Critical conditions identification	AGT_2	F	M
Graphical User Interface	Generated data and information visualization	GUI_1	F	M
	Maintenance actions reporting and recommendations	GUI_2	F	M
	Road operators inputs and instructions collection	GUI_3	F	M
	Mobile RWIS stations connection	GUI_4	F	M
Data Center Dispatcher	Front-ends requests management	DCD_1	F	M
	Multiple connections support	DCD_2	NF	M
Front-ends	Information delivery requests management	FE_1	F	M
	Front-ends isolation	FE_2	F	M
	Requests pre-validation	FE_3	F	M
	Requests forwarding service	FE_4	F	M
	Client requests & security management	FE_5	NF	M
	Authentication capability	FE_6	NF	M
	Interaction with external clients	FE_7	NF(I)	M
	Requests load management	FE_8	NF	M
Variable Message Signs front-end	Information type	VMSFE_1	F	M
	External client type	VMSFE_2	F	M
IP channels front-end	Data and information type	IPFE_1	F	M

Component	ID	Name	Type	Priority
Broadcast channels front-end	On-demand and periodic requests	IPFE_2	F	M
	Standard communication protocols and interfaces	IPFE_3	NF(I)	M
	Open data distribution licenses	IPFE_4	NF	M
	Information type	BFE_1	F	M
	Periodic requests	BFE_2	F	M
	Standard communication protocols and interfaces	BFE_3	NF(I)	M

Table 42: Complete list of CLEAN-ROADS requirements.

6.3 Overall system requirements

The CLEAN-ROADS must follow a reference set of high-level requirements identifying clearly (i) what the system is supposed to do and (ii) the principles on how its components should interact to one to each other and with external actors. These requirements represent a common reference for all specific requirements which will be defined for each single system component.

	System capability
ID	SC_1
Description	The system must be able to: • collect on a continuous temporal basis data of different nature concerning weather, road surface and traffic situation; • elaborate the gathered data on a real-time basis; • provide useful recommendations to the road maintenance staff based primarily on (i) generated data, (ii) generated information and (iii) specific weather bulletins provided by human meteorologists; • provide useful information to the travelers.
Rationale	Overall system target
Type	Functional
Priority	**M**

Table 43: Requirement SC_1 (system capability).

	"Open data" approach
ID	SC_2
Description	The system architecture must follow the open data principles for exposing any relevant raw / post-processed result (e.g. data, information, reports, etc.) that can be of some utility to third-party users of the system. The reference definition of open data is the one provided by a recent Italian national law, which states that[3]: • the data are available under the terms of a license that allows everybody to use it, even for commercial purposes; • the data are accessible through ICT systems and telematic networks, including the possibility for automatic use through specific software components; • the data are published for free or at marginal costs caused by its reproduction and dissemination[4].
Rationale	The "open data" approach will put the basis not only for a multiplication of possible travel information services to drivers, but also to maintain and possibly extend strong relationships with interested stakeholders (e.g. public administrations, research centers, and other private companies) in the direction of further

[3] Decreto-legge 18/10/2012 "Ulteriori misure urgenti per la crescita del paese", article 9.
[4] Fees can be accepted only in exceptional cases under the approval of the Digital Italy Agency (Agenzia per l'Italia Digitale)

	developments of the prototype system.
Type	Non-functional (interface)
Priority	**M**

Table 44: Requirement SC_2 ("open data" approach).

	Internal interoperability
ID	SC_3
Description	All the single components of the CLEAN-ROADS system must be able to interact one with each other through interfaces by using well defined and documented automatic services.
Rationale	The use of well documented interfaces will provide the system a high degree of modularity and thus of future scalability.
Type	Non-functional (interface)
Priority	**M**

Table 45: Requirement SC_3 (internal interoperability).

	Output delay
ID	SC_4
Description	The elaboration time of the system should be at maximum 15 minutes.
Rationale	The system must be able to update on a continuous time basis the (published) generated information concerning actual road conditions. This requirement does not apply for forecasts elaboration which will on the contrary follow a specific time schedule (e.g. N times a day).
Type	Non-functional (performance)
Priority	**M**

Table 46: Requirement SC_4 (output delay).

6.4 Remote systems requirements

Two main field measurement systems are going to be introduced through CLEAN-ROADS: static and mobile RWIS stations, which will collect road weather raw data at specific locations or along a certain route stretch, respectively. The following set of requirements describes the variables which are going to be measured by each system and gives some insights about how generated data (and information) are remotely managed, transferred and visualized.

6.4.1 Static RWIS station

	Data type
ID	SRS_1
Description	The static RWIS stations must be able to collect: • **weather** data; • **road surface condition** data.
Rationale	The road weather models need these classes of information in order to compute reliable forecasts of the road conditions
Type	Functional
Priority	**M**

Table 47: Requirement SRS_1 (data type).

	Data type (optional)
ID	SRS_2
Description	Additionally, the static RWIS stations should be able to collect: • **traffic** data; • **environmental** data.

Rationale	State-of-art road weather models do not typically consider these classes of data, but the availability of traffic data could allow to better model this factor in them, and the environmental data could provide very useful indications on the impacts generated by salting treatments.
Type	Functional
Priority	**S**

Table 48: Requirement SRS_2 (data type (optional)).

	Data type – weather data
ID	SRS_3
Description	The static RWIS stations must be able to take measurements of: • **air temperature;** • **relative humidity;** • **solar radiation;** • **barometric pressure;** • **precipitation (amount and type);** • **wind speed and direction.**
Rationale	The road weather models need mandatorily as input this set of weather data in order to compute reliable forecasts of the road conditions
Type	Functional
Priority	**M**

Table 49: Requirement SRS_3 (data type – weather data).

	Data type – weather data (optional)
ID	SRS_4
Description	Additionally, the static RWIS stations should be able to take measurements of: • **cloud cover;** • **visibility;** • **lightning.**
Rationale	State-of-art road weather models do not typically consider this weather data, but its availability could put in the condition to define and test very accurate models.
Type	Functional
Priority	**S**

Table 50: Requirement SRS_4 (data type – weather data (optional)).

	Data type – road surface conditions data
ID	SRS_5

Description	The static RWIS stations must be able to take measurements of:
	• **road surface temperature** (RST);
	• **road sub-surface temperature** (RSST);
	• **road surface conditions** (RSC), according to the reference EN 15518-3 standard classification:
	  ○ dry
	  ○ moist
	  ○ wet
	  ○ streaming water
	  ○ slippery

Rationale	The road weather models need mandatorily as input this set of road surface conditions data in order to compute reliable forecasts of the road conditions. RST and RSC are used for quantitatively assessing the accuracy of road weather models' forecasts as well.
Type	Functional
Priority	**M**

Table 51: Requirement SRS_5 (data type – road surface conditions data).

	Data type – road surface conditions data (optional)
ID	SRS_6
Description	Additionally, the static RWIS stations should be able to take measurements of: • **residual salt concentration;** • **soil temperature.**
Rationale	State-of-art road weather models do not typically consider this weather data, but its availability could put in the condition to define and test very accurate models.
Type	Functional
Priority	**S**

Table 52: Requirement SRS_6 (data type – road surface conditions data (optional)).

	Data type – traffic
ID	SRS_7
Description	The static RWIS stations should be able to detect traffic conditions, and collect e.g. the following measurements: • **number of vehicles** counted within the window observation; • **speed profile** i.e. all vehicles shall be classified in an aggregated way according to their speed to a speed class of maximum interval of 10 [km/h], with a lower boundary class 0-20 [km/h] and upper boundary class all speeds higher than 140 [km/h]; • **vehicle category** (according to the “9+1” classes Italian standard classification); • **travel direction**; • **gap**; • **headway**; • **lane** (in case of roads with multiple lane in the same direction); • **sensor occupation time**; • **vehicle length**; • **vehicle weight**.
Rationale	Traffic data can improve road weather models outputs and be used for useful correlation analysis.
Type	Functional
Priority	**S**

Table 53: Requirement SRS_7 (data type – traffic).

	Data type – environment
ID	SRS_8
Description	The static RWIS stations should be able to detect impacts on the surrounding environment, and more specifically on: • **air pollution**; • **run-off waters salinity**. The reference parameters to be measured are the environmental monitoring indicators listed in D.C2.1.
Rationale	Environmental data can provide a quantitative assessment of the impact of road maintenance activities and in particular of de-icing chemicals.
Type	Functional
Priority	**S**

Table 54: Requirement SRS_8 (data type – environment).

	Processing, transmission and other remote capabilities
ID	SRS_9
Description	The static RWIS stations must be designed such that: • **overall dimensions** are minimized; • electrical devices are properly **protected**;

	• **power consumption** is minimized; • **renewable power supplies** are considered where possible; • a **remote storage system** is available in order to maintain at least the measurements taken in the last few days; • data can be transmitted on a real-time basis through suitable **wired or wireless channels**; • **remote logic functionalities** are available in order to remotely carry out diagnostic activities; • **serial interfaces** for the connections with other authorized systems are available.
Rationale	Static RWIS systems must be in the condition to efficiently carry out the their detection functionalities through an optimum compromise between reliability and resources availability.
Type	Non-functional
Priority	**M**

Table 55: Requirement SRS_9 (processing, transmission and other remote capabilities).

6.4.2 Mobile RWIS station

	Basic data collection and information presentation functionalities
ID	MRS_1
Description	The mobile RWIS stations must be able to collect: • **RST** data; • **air temperature** data; • **maintenance activities** data. Moreover, they must be in the condition to present relevant information (e.g. real-time raw measurement, generated information sent by the MDSS, etc.) to the road operator through a proper **HMI**.
Rationale	Spatial indications about RST will improve the spatial resolution of route-based models outputs. The collection of air temperature gives the possibility to compute very detailed correlations with RST. Maintenance activities are recorded for several purposes, not only for having a quantitative evidence of the work done but also for technical reasons (e.g. correlations and elaboration purposes). Finally, the HMI can improve the on-board maintenance activities of the road operator (e.g. informing about a road weather event) and provide an immediate instrument for checking the proper functioning of the on-board equipment.
Type	Functional
Priority	**M**

Table 56: Requirement MRS_1 (data type).

	Data type (optional)
ID	MRS_2
Description	The mobile RWIS station must be in the condition to take at least one single reference RST measurement orthogonally to the travel direction. Optionally, **several RST detectors** could be used in order to characterize this variable along the cross-section of the road.
Rationale	Multiple parallel RST measurements will give the possibility to make advanced empirical studies, e.g. to identify RST variations between the centre of the lane and the road side.
Type	Functional
Priority	**S**

Table 57: Requirement MRS_2 (data type (optional)).

	Data type – position and timestamp

ID	MRS_3
Description	The mobile RWIS stations must be able to couple each measurement with the correspondent position and timestamp. Position must be characterized in terms of: • **coordinates** (referred to a standard spatial reference system); • **heading** (which is the compass direction toward which the mobile probe is moving);
Rationale	This metadata is of fundamental importance in order to properly process the generated data.
Type	Functional
Priority	**M**

Table 58: Requirement MRS_3 (data type - position and timestamp).

	Data type – maintenance activities
ID	MRS_4
Description	The mobile RWIS stations must be able to record maintenance activities. In particular, the following parameters must be considered: • **vehicle identifier**; • **road operator identifier**; • **beginning instant** of the activity (timestamp) • **ending instant** of the activity (timestamp) • **activity type** (e.g. de-icing treatment, snow removal operation); • **associated activity track**. Associated to the activity type, in case of road salting, the generated data must contain also the following variables: • **salt flux** [g/m²] • **spreading width** [m]
Rationale	Maintenance activities are recorded for several purposes, not only for having a quantitative evidence of the work done but also for technical reasons (e.g. correlations and elaboration purposes)
Type	Functional
Priority	**M**

Table 59: Requirement MRS_4 (data type – maintenance activities).

	Data type – maintenance activities (optional)
ID	MRS_5
Description	Additionally, the mobile RWIS stations should be able to record further data concerning maintenance activities or road operators' alerts, e.g.: • notification about eventual **damages occurred during the treatment activities**; • notifications about **road infrastructure damages**; • **accident alerts**.
Rationale	Additional data recording could improve the monitoring capabilities of treatment activities and also exploit this functionality in order to collect further information concerning road status.
Type	Functional
Priority	**S**

Table 60: Requirement MRS_5 (data type – maintenance activities (optional)).

	Data type – CAN bus data
ID	MRS_6
Description	The mobile RWIS stations should be able to extract **additional data available on the vehicular CAN bus** (e.g. status of the windscreen wipers or rain sensors, the air–conditioning system, vehicle's light system, hazard warning flashers, vehicle

	dynamics control system, and data collected by the external thermometer and other ADAS).
Rationale	Vehicular data available on the CAN bus network could provide additional indications that could be efficiently integrated in the processing chain.
Type	Functional
Priority	**S**

Table 61: Requirement MRS_6 (data type – CAN bus data).

	Processing, transmission and other remote capabilities
ID	MRS_7
Description	The mobile RWIS stations must be designed such that: • **overall dimensions** are minimized; • electrical devices are properly **protected**; • **power consumption** is minimized; • a **remote storage system** is available in order to maintain at least the measurements taken during a thermal mapping activity; • data can be transmitted on a real-time basis through suitable **wireless channels**; • **remote logic functionalities** are available in order to (i) properly control the additional on-board electronic devices installed in order to accomplish the aforementioned functionalities and (ii) display remote measurements and eventually information sent by the MDSS on a proper HMI.
Rationale	Mobile RWIS systems must be in the condition to efficiently carry out the their detection and data presentation functionalities through an optimum compromise between reliability, road operators' comfort and safety as well as resources availability.
Type	Non-functional
Priority	**M**

Table 62: Requirement MRS_7 (processing, transmission and other remote capabilities).

6.5 Data sources requirements

Each data source of the CLEAN-ROADS system is in charge to receive in input data streams of well-defined classes of data types (i.e. road conditions data, weather data or forecasts, traffic data, etc.), pre-validate them and to put this data at disposal of an upper level of the central system where it will be stored and elaborated. Thanks to this architecture, all data sources are in the condition to eventually receive in the future data coming from other 3rd parties sources (e.g. existing fleets of vehicles, monitoring stations of external manufacturers), which may (or may not) satisfy the requirements defined in the previous paragraph. In this way, a high potential in terms of interoperability and future system exploitations is guaranteed.

A list of reference requirements shared by all different data source is presented in the following tables.

	Data gathering
ID	DS_1
Description	Any data source must be able to receive data transmitted by only one or more sources which are in charge to collect measurements on specific data types, depending on their monitoring tasks.
Rationale	Data sources specificity
Type	Functional
Priority	**M**

Table 63: Requirement DS_1 (data gathering).

	Data source isolation
ID	DS_2
Description	Any data-source must be an independent entity with respect to the other data-sources and the data center collector.
Rationale	This architecture choices guarantees higher performance in terms of flexibility, stability and exploitation.
Type	Functional
Priority	**M**

Table 64: Requirement DS_2 (data source isolation).

	Data packets validation
ID	DS_3
Description	Any data-source must be able to run automatic validation routines on the data in order to check if: • the pre-defined **data type formats** are satisfied; • the **data packets are formatted** in a different manner with respect to what is expected; • **outlayers** or other unreliable data values are present. In case data do not comply with expected formats, these packets must be <u>dropped</u> by the data source. In case of outlayers detection, these must be only properly <u>flagged</u> and in any case forwarded to the Data Central Collector.
Rationale	This functionality simplifies the following data management and processing tasks.
Type	Functional
Priority	**M**

Table 65: Requirement DS_3 (data packets validation).

	Data source forwarding service
ID	DS_4
Description	Any data source must forward all validated data to the upper level of the architecture (i.e. the Data Center Collector).
Rationale	Validated data must be available at further levels in the architecture for storing and processing purposes.
Type	Functional
Priority	**M**

Table 66: Requirement DS_4 (data source forwarding service).

	Source position
ID	DS_5
Description	Any data-source must be able to couple the generated data with the geographic position of the related source.
Rationale	It is important to know which remote system is transmitting the data and the specific location they refer to.
Type	Functional
Priority	**M**

Table 67: Requirement DS_5 (source position).

	Source status information
ID	DS_6
Description	Any data-source should be able to receive source status information coupled with generated data. In case this applies, the data source should extend its validation capabilities by properly marking data packets collected under specific sources malfunctioning conditions.
Rationale	This functionality further simplifies the following data management and processing

	tasks.
Type	Functional
Priority	**S**

Table 68: Requirement DS_6 (source status information).

	Warning capabilities
ID	DS_7
Description	Any data-source should be able to generate warnings in case some of the data packets have not passed all validation controls, or in case of some security issues (e.g. unauthorized client trying to send data).
Rationale	Thanks to this functionality it would be possible to improve the maintenance capabilities of the entire RWIS.
Type	Functional
Priority	**S**

Table 69: Requirement DS_7 (warning capabilities).

	Source trustworthiness
ID	DS_8
Description	Any data source must have the necessary capabilities in order to guarantee that the generated data are delivered by a trusted source.
Rationale	Prevent spoofing attacks.
Type	Non-functional
Priority	**M**

Table 70: Requirement DS_8 (source trustworthiness).

	Authentication capability
ID	DS_9
Description	Any data source must be able to authenticate itself with the Data Center Collector in order to be able to forward the gathered data.
Rationale	Guarantee a secure workflow.
Type	Non-functional
Priority	**M**

Table 71: Requirement DS_9 (authentication capability).

	Data timestamp
ID	DS_10
Description	Any generated data which is delivered to a data source must be coupled with the timestamp of the monitoring instant.
Rationale	It is fundamental to couple generated data with the associated monitoring instant in order to properly process the data.
Type	Non-functional
Priority	**M**

Table 72: Requirement DS_10 (data timestamp).

	Source identification
ID	DS_11
Description	Any data source must send to the Data Center Collector the received data streams coupled with the unique identity of the corresponding source.
Rationale	It is important to couple generated data with the associated source and not lose this association at this stage.
Type	Non-functional
Priority	**M**

Table 73: Requirement DS_11 (source identification).

	Source interoperability

ID	DS_12
Description	Any data source must use standard interfaces and/or well defined and documented protocols to gather the generated data from the related sources.
Rationale	The use of standard interfaces and/or well defined and documented protocols guarantees the maximum interoperability.
Type	Non-functional (interface)
Priority	**M**

Table 74: Requirement DS_12 (source interoperability).

	Elaboration time
ID	DS_13
Description	The total amount of time which is needed by every data-source to (i) gather the generated data, (ii) perform the validation controls and (iii) forward the validated data to the Data Center Collector has to be negligible with respect to the total elaboration time.
Rationale	Most of the delay generated by the overall processing chain must be located in correspondence of the elaboration tasks.
Type	Non-functional (performance)
Priority	**M**

Table 75: Requirement DS_13 (elaboration time).

6.5.1 Weather forecasts data source

This data source is in charge to collect the data coming from the automatic numerical weather prediction (NWP) models, which is needed in order to compute the forecasts of the road conditions.

	Data type
ID	WFDS_1
Description	The forecast data gathered from external NWP models must contain at least the following parameters: • **air temperature**; • **dew point**; • **rain precipitation** quantity since the beginning of the forecast; • **snow precipitation** quantity since the beginning of the forecast; • **wind speed**; • **surface pressure**; • **cloud coverage**; • **relative humidity**; • **wind direction**; • **precipitation rate**.
Rationale	Basic data set that is requested by road weather forecasts models.
Type	Functional
Priority	**M**

Table 76: Requirement WFDS_1 (data type).

	Data type (optional)
ID	WFDS_2
Description	The forecast data gathered from external NWP models should additionally cover the following parameters: • **high cloud cover**; • **medium cloud cover**; • **low cloud cover**; • **short wave incident radiation**;

	• **long wave incident radiation**.
Rationale	Additional data that can be included in more complicated road weather forecasts models
Type	Functional
Priority	**S**

Table 77: Requirement WFDS_2 (data type (optional)).

	Data format
ID	WFDS_3
Description	All the generated data received by this data source from external NWP models must be formatted in accordance to reference standard (e.g. GRIB, GRIB2).
Rationale	The use of reference data formats protocols simplifies the possibility to include in the future the outputs of further NWPs.
Type	Non-functional (interface)
Priority	**M**

Table 78: Requirement WFDS_3 (data format).

	Data frequency update
ID	WFDS_4
Description	The weather forecasts data source must be able to gather the output data of the considered NWP models whenever they are updated.
Rationale	This approach guarantees the maximum performance and the minimum processing delays
Type	Non-functional (performance)
Priority	**M**

Table 79: Requirement WFDS_4 (data frequency update).

6.5.2 Static RWIS station data source

Static and mobile RWIS stations data source are the specific end-points at the central back-office system in charge of properly receiving the generated data from the static and mobile RWIS stations, respectively. Data transfer constraints are indicated in the following set of requirements.

	Data frequency update – mandatory data types
ID	SRSDS_1
Description	The maximum time interval between two consecutive generated data packets containing mandatory data types (i.e. weather and road surface condition data) source must be 5 minutes.
Rationale	Possibility to process on a real-time basis the generated data collected by the static RWIS stations.
Type	Non-functional (performance)
Priority	**M**

Table 80: Requirement SRSDS_1 (data frequency update – mandatory data types).

	Data frequency update – optional data types (traffic)
ID	SRSDS_2
Description	The maximum time interval between two consecutive generated data packets containing traffic parameters only delivered to the static data source must be 5 minutes.
Rationale	Possibility to additionally process on a real-time basis the traffic-related generated data collected by the static RWIS stations.
Type	Non-functional (performance)

Priority	**S**

Table 81: Requirement SRSDS_2 (data frequency update – optional data types (traffic)).

	Data frequency update – optional data types (environment)
ID	SRSDS_3
Description	The maximum time interval between two consecutive generated data packets containing air pollution parameters only delivered to the static data source must be 15 minutes. Run-off waters salinity measurements are not likely to be transferred on a real-time basis to the system, since water samples must be manually gathered and analyzed in laboratory first.
Rationale	Possibility to additionally process on a real-time basis the air pollution-related generated data collected by the static RWIS stations.
Type	Non-functional (performance)
Priority	**S**

Table 82: Requirement SRSDS_3 (data frequency update – optional data types (environment)).

6.5.3 Mobile RWIS station data source

	Data frequency update
ID	MRSDS_1
Description	The maximum time interval between two consecutive generated data packets delivered to the mobile RWIS station data-source must be 5 minutes.
Rationale	Possibility to process on a real-time basis the generated data collected by the mobile RWIS stations.
Type	Non-functional (performance)
Priority	**M**

Table 83: Requirement MRSDS_1 (data frequency update).

	Road weather and maintenance activities data packets independency
ID	MRSDS_2
Description	The data source must be able to receive separately data packets related to one side RST and air temperature data (road weather sensors) and on the other side road maintenance activities recordings (tracking equipment).
Rationale	Data types managed by the mobile RWIS stations have different nature, so it could be possible to design the data source in a way that the different generated data streams can follow completely independent processing chains.
Type	Non-functional
Priority	**M**

Table 84: Requirement MRSDS_2 (road weather and maintenance activities data packets independency).

6.5.4 Local manual-driven forecasts collector

The local manual-driven forecasts collector is a component of the system architecture which is in charge to receive the periodic forecasts generated by the human meteorologists experts that are specifically determined for road maintenance purposes. These forecasts are going to contain a simplified presentation of the expected evolution of a certain number of road weather variables.

	Data type
ID	MDFC_1
Description	Each manual-driven forecast received by this collector must contain, in a human simplified representable form, at least the following information: • the expected forecasted evolution of meteorological parameters such as

	relative humidity, temperature, wind, precipitation; • the probability of **ice formation** and **snow accumulation** on the road surface.
Rationale	Road maintenance staff can actively consider these recommendations in their decision-making process
Type	Functional
Priority	**M**

Table 85: Requirement MDFC_1 (data type).

	Data frequency update
ID	WFDS_2
Description	The maximum time interval between two consecutive manual-driven forecasts generated by the same external entity must be 24 [hours].
Rationale	Typical time interval for the generation of weather forecasts; each manual-driven forecast can support the road maintenance operations in the 12 [h] and support either “daily” or “nocturnal” activities.
Type	Non-functional (performance)
Priority	**M**

Table 86: Requirement MDFC_2 (data frequency update).

6.5.5 Weather data source

The weather data source is responsible for the reception and validation of the flows of meteorological data coming from a variety of weather stations installed within the Autonomous Province of Trento (and not only) and managed by a variety of public / private organizations. The inclusion of this information in the central system can enrich the overall monitoring capabilities of the road maintenance service, e.g. by checking if particular precipitation events have started at specific locations of the region.

	Data type
ID	WDS_1
Description	The data gathered by this data source which come from a local weather station must contain at list the following fields: • **air temperature and humidity;** • **wind direction and speed;** • **type and intensity of precipitation**.
Rationale	Minimal meteorological information that is of interest for the road maintenance staff.
Type	Functional
Priority	**M**

Table 87: Requirement WDS_1 (data type).

	Provider and weather stations identification
ID	WDS_2
Description	The weather data source must be in the condition to couple each data packet not only to the weather station that has collected it but also to the organization responsible for its management and control.
Rationale	It is important to couple generated data with the associated metadata and not lose this association at this stage.
Type	Non-functional
Priority	**M**

Table 88: Requirement WDS_1 (provider and weather stations identification).

	Data frequency update
ID	WDS_3
Description	The maximum time interval between two consecutive generated data packets delivered to the weather data-source by the same weather station must be 15 minutes
Rationale	This approach guarantees to maximize the compromise between data generation and transmission costs and data freshness for real-time applications.
Type	Non-functional (performance)
Priority	**M**

Table 89: Requirement WFDS_3 (data frequency update).

6.5.6 Traffic data source

The traffic data source is responsible for the reception and validation of the flows of traffic data coming from a variety of existing traffic detections stations installed within the Autonomous Province of Trento (and not only). The inclusion of this information in the central system can extend the monitoring capabilities of the road maintenance staff, and check for example the impact that meteorological conditions are having on traffic flows. An integrated road / weather / traffic-oriented approach for the maintenance of the road network is therefore possible. Data types and frequency update requirements are in line with the indications already given for the static RWIS stations.

	Data type
ID	TDS_1
Description	The data packets received by the traffic data source must contain at least; • **number of vehicles** counted within the window observation; • **speed profile** i.e. all vehicles shall be classified in an aggregated way according to their speed to a speed class of maximum interval of 10 [km/h], with a lower boundary class 0-20 [km/h] and upper boundary class all speeds higher than 140 [km/h]; • **vehicle category** (according to the "9+1" classes Italian standard classification); • **travel direction**; • **gap**; • **headway**; • **lane** (in case of roads with multiple lane in the same direction); • **sensor occupation time**; • **vehicle length**; • **vehicle weight**.
Rationale	Basic traffic information that can be useful for joint traffic / weather assessments.
Type	Functional
Priority	**M**

Table 90: Requirement TDS_1 (data type).

	Data type (web cams)
ID	TDS_2
Description	The traffic data source must be able to properly receive the video streams coming from roadside web cams showing the actual evolution of traffic flows.
Rationale	"Visual" traffic information that can be immediately checked by the road maintenance staff.
Type	Functional
Priority	**M**

Table 91: Requirement TDS_2 (data type (web cams)).

	Data type (optional)
ID	TDS_3
Description	The data packets received by the traffic data source should additionally contain the following parameters; • **gap**; • **headway**; • **lane** (in case of roads with multiple lane in the same direction); • **sensor occupation time**; • **vehicle length**; • **vehicle weight**.
Rationale	Optional traffic information that can further improve joint traffic / weather monitoring activities.
Type	Functional
Priority	**S**

Table 92: Requirement TDS_3 (data type (optional)).

6.5.7 3rd parties end-point

The 3rd parties end-point has the double role to receive road weather information generated by other neighbouring organizations responsible for the road maintenance of other road networks but also to transmit the internally generated information that are considered to be relevant for them.

	Information type
ID	3PEP_1
Description	The information that can be managed by the 3rd parties end point must belong one of the following categories: • **road surface conditions;** • **road weather conditions and events;** • **traffic events;** • **VMS messages.**
Rationale	Basic set of information categories that can be useful for joint, extended road maintenance purposes.
Type	Functional
Priority	**M**

Table 93: Requirement 3PEP_1 (information type).

	Standard format
ID	3PEP_2
Description	The 3rd parties end-point must be able to exchange the information indicated in requirements 3PEP_1 using a standard communication protocol such as DATEX II.
Rationale	This architecture choice guarantees an immediate interoperability between different involved organizations.
Type	Non-functional
Priority	**M**

Table 94: Requirement 3PEP_2 (standard format).

	Data exchange frequency update
ID	3PEP_3
Description	The 3rd parties end-point must be able to properly manage the information based on its reference category and to exchange it (i) based on the time delivery modalities defined by the other 3rd parties organization and (ii) based on the typology of the information that needs to be published, which can follow a

	periodical refresh approach in case of road surface – or road weather conditions updates, as well as VMS messages, as well as a “triggering” approach in case of road weather events.
Rationale	This approach allows to optimally manage the information reception and transmission operations.
Type	Non-functional
Priority	**M**

Table 95: Requirement 3PEP_3 (data exchange frequency update).

	Client authentication and authorization
ID	3PEP_4
Description	The 3rd parties end point must have the necessary capabilities and resources to authenticate and authorize any external 3rd party.
Rationale	Secure transmission exchange of the available information.
Type	Non-functional
Priority	**M**

Table 96: Requirement 3PEP_4 (client authorization).

6.6 MDSS requirements

The MDSS is the core of the entire RWIS, where the data are centrally stored, aggregated and elaborated. Two types of automatic processing operations are going to be supported, namely (i) the computation of actual and forecasted route-based road conditions maps and (ii) the generation of proper alarms that can be in the condition to properly trigger the activities of the road maintenance staff. The outputs of these automatic processing operations, as well as all the different input data collected by the different sources, are going to be properly visualized through a GUI to this specific category of users. A common set of requirements which apply for this part of the system as a whole is reported in the tables below.

	MDSS capabilities
ID	MDSS_1
Description	The MDSS must be able to: • **collect and store the generated data and information** produced by the automatic elaboration routines, and, where necessary, all relevant intermediate elaboration products; • **coordinate the activities of the automatic data elaboration routines;** • **make validated data and elaboration outputs properly accessible** to the road maintenance staff through a dedicated GUI and to external information distribution channels.
Rationale	Boundary of the basic functionalities that need to be supported by the MDSS.
Type	Functional
Priority	**M**

Table 97: Requirement MDSS_1 (MDSS capabilities).

	MDSS security
ID	MDSS_2
Description	The MDSS must present sufficient protection measures in order to prevent any kind of external attacks and thus maximize the overall security. In case of intrusion or other system violation, proper notifications must be immediately transmitted to the authorized staff.
Rationale	Ensure that the MDSS is sufficiently secure against external malicious attacks.
Type	Non-functional

Priority	**M**

Table 98: Requirement MDSS_2 (MDSS security).

	MDSS performance
ID	MDSS_3
Description	The MDSS must be able to process the entry data and information in a “real-time” mode, so that requirement SC_4 is properly satisfied
Rationale	The MDSS must be designed in a way to guarantee the expected temporal performance of the entire RWIS.
Type	Non-functional (performance)
Priority	**M**

Table 99: Requirement MDSS_3 (MDSS performance).

	MDSS flexibility and scalability
ID	MDSS_4
Description	The MDSS must be designed in a way in order to guarantee a high degree of flexibility and scalability for matching present but also future needs
Rationale	Easy possibility to further exploit the system after the project
Type	Non-functional (performance)
Priority	**M**

Table 100: Requirement MDSS_3 (MDSS flexibility and scalability).

6.6.1 Data Center Collector

The Data Center Collector (DCC) is the component of the MDSS which is responsible to centrally aggregating all the different data flows that are made available at the data sources layer and to properly store in the database.

	Uniqueness
ID	DCC_1
Description	The DCC must be the unique collection point for all data-sources.
Rationale	The choice of having only one single aggregation point directly connected to the DB can provide high performances in terms of system scalability and security.
Type	Functional
Priority	**M**

Table 101: Requirement DCC_1 (uniqueness).

	Source and data source identification
ID	DCC_2
Description	The DCC must be able to identify the data source which is providing the data, and where appropriate the external source which has generated it.
Rationale	Data must be aggregated by properly associating to it a set of useful metadata
Type	Functional
Priority	**M**

Table 102: Requirement DCC_2 (source and data source identification).

	Database connection
ID	DCC_3
Description	The DCC must be able to connect to the database and to store the data on the base of its specifications.
Rationale	This is the basic functionality expected to be guaranteed by the DCC.
Type	Functional
Priority	**M**

Table 103: Requirement DCC_3 (database connection).

	Authentication and security
ID	DCC_4
Description	The DCC must authenticate itself to the database.
Rationale	Storing activities must be performed in a secure way.
Type	Non-functional
Priority	**M**

Table 104: Requirement DCC_4 (authentication and security).

	Data source authentication management
ID	DCC_5
Description	The DCC must be able to manage the authentication process of the underlying data sources, as explained in requirement DS_9.
Rationale	Data transfer activities must be performed in a secure way.
Type	Non-functional
Priority	**M**

Table 105: Requirement DCC_5 (data sources authentication management).

	Multiple connections support
ID	DCC_6
Description	The Data Center Collector must have the capability to properly open and manage multiple connections with one or more data sources. The presence of other open connections must be as much as transparent as possible for a data source, and not produce significant delays in the generated data transfer.
Rationale	Data sources can transmit data to the DCC in parallel; the DCC must be designed in order to properly address this scenario.
Type	Non-functional
Priority	**M**

Table 106: Requirement DCC_6 (multiple connections support).

6.6.2 Database

The database is the location of the MDSS where generated data and information are stored. The proposed set of requirements aim cover almost all different aspects that must be typically considered in the design and implementation process of a database.

	GIS capability
ID	DB_1
Description	The database must be spatial, i.e. able to store and handle geo-referenced data.
Rationale	The spatial extension of the database is necessary in order to properly process the available data and manage the spatial generated information (e.g. the route-based forecasts).
Type	Functional
Priority	**M**

Table 107: Requirement DB_1 (database).

	Generated data storing capability
ID	DB_2
Description	The database must be able to store all the data received by the DCC.
Rationale	Actually, for the purposes of the road maintenance tasks not all the generated data need to be stored, e.g. the video streams of the web cams, but it would be necessary just to visualize it in the GUI; the database must be however capable to save everything.
Type	Functional
Priority	**M**

Table 108: Requirement DB_2 (generated data storing capability).

	Elaboration outputs and alarms storing capability
ID	DB_3
Description	The database must be able to store (i) the elaboration outputs produced by the route-based elaboration & forecasting engine (and if appropriate the intermediate products as well), and (ii) the alarms generated by the alarms generation tool.
Rationale	The database must be in the condition to store not only the "raw" generated data but also the outputs of automatic routines run on top of it.
Type	Functional
Priority	**M**

Table 109: Requirement DB_3 (elaboration outputs and alarms storing capability).

	History and export capability
ID	DB_4
Description	The database must be able to efficiently manage all the storing "history" associated to generated data and information, and to export a part or even the entire set of data stored.
Rationale	It has to be possible to access to old data and information as well for comparison purposes or statistical studies.
Type	Functional
Priority	**M**

Table 110: Requirement DB_4 (history capability).

	Logging, reports and warning management
ID	DB_5
Description	The database should be able to log transactions and to generate standard reports, as well as to properly handle warnings.
Rationale	It should be possible to efficiently keep trace of database transactions.
Type	Functional
Priority	**S**

Table 111: Requirement DB_5 (logging and reports).

	Data incorruptibility & security
ID	DB_6
Description	The database must guarantee that stored data are not corrupted over time, and that accesses to it are performed in a secure way.
Rationale	Basic database performance requirements.
Type	Non-functional
Priority	**M**

Table 112: Requirement DB_6 (data incorruptibility & security).

	Interfaces
ID	DB_7
Description	An external access to the database is allowed only to: • **Data Center Collector;** • **route-based elaboration & forecasting engine;** • **alarms generation tool;** • **graphical user interface.** The route-based elaboration & forecasting engine as well the alarms generation tool must be able to access all the kind of data that are needed to carry out the processing tasks, and store its generated outputs in the database.
Rationale	For security and performance reason, the access to the tables of the database is limited to the different components of the MDSS.
Type	Non-functional (interface)

Priority	**M**

Table 113: Requirement DB_7 (interfaces).

	Performance
ID	DB_7
Description	The time needed by the database for the storing activities of generated data must be negligible if compared to the total system elaboration time indicated in requirement SC_4.
Rationale	Most of the "delay" generated by the system must be associated to the processing tasks done by the route-based elaboration and forecasting engine and the alarms generation tool.
Type	Non-functional (performance)
Priority	**M**

Table 114: Requirement DB_8 (performance).

6.6.3 Route-based elaboration & forecasting engine

The route-based elaboration & forecasting engine is the main processing component of the entire RWIS. Based on the variety of available road weather data and weather forecasts, this engine is supposed to generate route-based maps of the current road network conditions as well their prediction in the short-term period.

	Road surface conditions – actual situation assessment
ID	REFE_1
Description	The route-based elaboration & forecasting engine must be able to provide, based on available mobile and static RWIS data, an assessment of the **actual road conditions situation**. This must be available both in numerical form with reference to specific parameters (e.g. road surface temperature) and in a "classified" form, i.e. with a clear association to one of pre-coded road surface conditions class. In this sense, a compatibility with the coding indications given in the EU standard EN 15518 must be considered. This routine must be run in correspondence of new data records entries in the database.
Rationale	Static and mobile RWIS stations data must be processed in order to give a human comprehensive overview of the actual road conditions situation, which can be of particular importance for sudden and proper countermeasures action by the road maintenance staff.
Type	Functional
Priority	**M**

Table 115: Requirement REFE_1 (road surface conditions – actual situation assessment).

	Road surface conditions – forecasted situation assessment
ID	REFE_1
Description	The route-based elaboration & forecasting engine must be additionally able to give on a periodic basis an indication of the **forecasted road conditions situation**, up to a time horizon of 12 [h]. The elaboration output must be available as recommended in the requirement REFE_1.
Rationale	Weather forecasts combined with static and mobile RWIS stations data must be processed in order to give a human comprehensive overview of the forecasted road conditions situation, and thus to give useful inputs for the preparation and organization of road treatments activities.
Type	Functional
Priority	**M**

Table 116: Requirement REFE_2 (road surface conditions – forecasted situation assessment).

	Road surface conditions – forecasted situation assessment

ID	REFE_1
Description	The route-based elaboration & forecasting engine must be additionally able to give an indication of the **forecasted road conditions situation**, up to a time horizon of 12 [h]. The elaboration output must be available as recommended in the requirement REFE_1.
Rationale	Weather forecasts combined with static and mobile RWIS stations data must be processed in order to give a human comprehensive overview of the forecasted road conditions situation, and thus to give useful inputs for the preparation and organization of road treatments activities.
Type	Functional
Priority	**M**

Table 117: Requirement REFE_2 (road surface conditions – forecasted situation assessment).

	Elaboration outputs formats
ID	REFE_3
Description	The automatic processing tasks defined in requirements REFE_1 and REFE_2 must produce geo-spatial outputs that are immediately visualizable through a GIS.
Rationale	By guaranteeing this spatial functionality support, the generated information produced by the route-based elaboration & forecasting engine can be immediately displayed in a human understandable form.
Type	Non-functional
Priority	**M**

Table 118: Requirement REFE_3 (elaboration outputs formats).

	Spatial resolution
ID	REFE_4
Description	The spatial resolution of the automatic routines managed by the route-based elaboration & forecasting engine must be at maximum 100 [m], but with the possibility to increase it in the order of 50 [m] thanks to the data provided by the mobile RWIS stations.
Rationale	The indicated maximum spatial resolution is compatible with the effective treatments' needs of the road maintenance staff.
Type	Non-functional (performance)
Priority	**M**

Table 119: Requirement REFE_4 (spatial resolution).

6.6.4 Alarms generation tool

The alarm generation tool is a component of the MDSS which has a twofold role, i.e. to (i) automatically process the data in order to find out calibration and malfunctioning problems, and (ii) trigger specific set of alerts to the road maintenance staff in case critical road conditions are detected or predicted.

	Calibration and malfunctioning problems discovery
ID	AGT_1
Description	The alarms generation tool must be in the condition to pre-process the data coming from the CLEAN-ROADS sources (i.e. transmitted to the weather forecasts data sources, the mobile – and static RWIS station data sources) as soon as there is a new entry record in the database, in order to find out outlayers and other unreliable data which are caused by calibration sensors problems or any other malfunctioning at the sources side. This data must be properly marked so that this information can be properly managed by the route-based elaboration & forecasting engine.
Rationale	It is important that the processing algorithms are applied on reliable data. It is

	worth noting that these controls are not applied on other data flows provided by other data sources since they are not directly involved in this processing chain.
Type	Functional
Priority	**M**

Table 120: Requirement AGT_1 (calibration and malfunctioning problems discovery).

	Critical conditions identification
ID	AGT_2
Description	The alarms generation tool must be able to automatically process generated data as well the generated information produced by the route-based elaboration & forecasting engine in order to identify conditions that may put at risk the normal road safety conditions.
Rationale	This functionality aims to automatically put in evidence situations that are of interest for the road maintenance staff, and therefore must be extended, if necessary to the sources that are outside the CLEAN-ROADS system's boundary (e.g. snowfall event has started in a neighboring road infrastructure).
Type	Functional
Priority	**M**

Table 121: Requirement AGT_2 (critical conditions identification).

6.6.5 Graphical User Interface

The GUI is the front-end part of the MDSS to the road maintenance staff, which is in charge to present the variety of generated data and information in a smart way so that they can immediately get an overview of the road conditions' situation in the monitored area and thus prepare their activities accordingly. Their role is not only passive: an active relationship is foreseen, in particular in the direction of manually supervising the set of information messages to be sent through the ATIS.

	Generated data and information visualization
ID	GUI_1
Description	The GUI must be in the condition to display <u>in both textual and map-based</u> form both the **generated data** as well the **outputs of the automatic routines**. This big amount of information must be presented to the road maintenance staff in a <u>human understandable form</u> (e.g. by using plots and other suitable graphical representations), <u>ordered by type of information</u> (e.g. traffic versus road conditions versus weather situation and forecasts) and <u>priority</u> (i.e. alarms must be displayed first).
Rationale	The road maintenance staff must be in the condition to immediately assess the status of the road network, but also in case of necessity to get all the data details which is needed in order to take a decision of a certain maintenance action. The GUI must be designed in a way that the functionalities are immediately understandable with very little or no training of the users of this software platform.
Type	Functional
Priority	**M**

Table 122: Requirement GUI_1 (generated data and information visualization).

	Maintenance actions reporting and recommendations
ID	GUI_2
Description	The GUI must be able to include both (i) **suggestions of the road maintenance activities** to be carried out, and (ii) the **activity reports collected by the mobile RWIS stations**. The presentation of this information must follow the indications given in the requirement GUI_1.
Rationale	The road maintenance staff shall not only have a representation of actual and

	forecasted road weather conditions, but have on one side a direct indication of the necessity / type of road treatments to be carried out, and on the other side an instrument for visualizing the effective treatment activities carried out by road operators. It is worth noting that in any case the final decision is in charge of the human operators, and the MDSS represents only a tool for the definition of actions based on objective considerations and facts.
Type	Functional
Priority	**M**

Table 123: Requirement GUI_2 (maintenance actions reporting and recommendations).

	Road operators inputs and instructions collection
ID	GUI_3
Description	The GUI must be able in general to collect and, where relevant, to store **inputs coming from a specific set of authorized users of the GUI**. The intervention of the human experts is in particular required in order to manually supervise the publication of information and messages destined to the local travelers through the ATIS, especially to obtain a certain traffic equilibrium in the road network.
Rationale	Despite most of the information destined to the local travelers can be automatically generated, the role of traffic experts is important in order to properly manage and control this information flow to the end-users. An example of this is the decision to publish a certain pre-coded message on the network of Variable Message Signs.
Type	Functional
Priority	**M**

Table 124: Requirement GUI_3 (road operators inputs and instructions collection).

	Mobile RWIS stations connection
ID	GUI_4
Description	The GUI must have a “special” direct connection to the mobile RWIS stations, in order to allow the road operator on-board managing the road treatments’ activities while on the field to compare through a proper HMI the actual road surface conditions which are centrally computed by the MDSS with the field data that the on-board sensors are measuring and eventually with the specific treatments he is carrying out.
Rationale	The road operator can have while on the road an on-board assistance of the maintenance tasks he is doing and eventually further optimizing the treatment actions in a dynamic way. An optimal compromise must be however find out in order to not increase the driver’s distraction while he is driving.
Type	Functional
Priority	**M**

Table 125: Requirement GUI_4 (mobile RWIS stations connection).

6.7 ATIS requirements

The ATIS is an additional subystem of the CLEAN-ROADS architecture which gives the possibility to put in direct contact the MDSS with the existing (and future) traveler information channels. A business-to-business approach is suggested so that it is possible for the Autonomous Province of Trento to have not only its own information channels but to create win-win partnerships with external service providers interested in delivering this and other traffic-related information to the end-users.

6.7.1 Data Center Dispatcher

The Data Center Dispatcher (DCD) can be seen as a dual component with respect to the DCD. The requests coming from the service providers through the different front-ends are centrally managed by this component in direct contact with the GUI which is already “internally” publishing the available generated data and information.

	Front-ends requests management
ID	DCD_1
Description	The DCD must properly gather the requests coming from the front-ends and return the requested information that are destined to that particular traveler information channel type.
Rationale	The DCD must act as a central point for the proper translation of the different front-ends requests.
Type	Functional
Priority	**M**

Table 126: Requirement DCD_1 (front-ends requests management).

	Multiple connections support
ID	DCD_2
Description	The DCD must have the capability to properly open and manage multiple connections with one or more front-ends. The presence of other open connections must be as much as transparent as possible for a front-end, and not produce significant delays in the generated data transfer.
Rationale	Front-ends can transmit requests to the DCD in parallel; the DCD must be designed in order to properly address this scenario.
Type	Non-functional
Priority	**M**

Table 127: Requirement DCD_2 (multiple connections support).

6.7.2 Front-ends

The front-ends are the end-point of the CLEAN-ROADS system in terms of information distribution to the public; they can be contacted by external services wanting to get the real-time information managed by the RWIS and transmitting it to the local travellers through a specific service or application (e.g. smartphones app, online or broadcasted services, etc.). A specific use case is the one related to the VMS front-end which are directly connected to the network of VMSs.The basic set of requirements that are shared by all front-ends is presented in the following tables.

	Information delivery requests management
ID	FE_1
Description	Any front-end must be able to be contacted by one or more specific and supported external clients wanting to have access to certain validated information published by the GUI, and return to them the associated information set.
Rationale	The external service providers must have the front-ends as communication end point for retrieving specific information coming from the RWIS.
Type	Functional
Priority	**M**

Table 128: Requirement FE_1 (information delivery requests management).

	Front-ends isolation
ID	FE_2
Description	Any front-end must be a virtual independent entity with respect to the other front-ends and the Data Center Dispatcher.
Rationale	This is an architecture choice which maximizes scalability opportunities.
Type	Functional
Priority	**M**

Table 129: Requirement FE_2 (front-ends isolation).

	Requests pre-validation
ID	FE_3
Description	Any front-end must drop all received requests that are formatted in a different manner as expected.
Rationale	The incoming requests must follow the specifications of the exposed web-services.
Type	Functional
Priority	**M**

Table 130: Requirement FE_3 (requests pre-validation).

	Requests forwarding service
ID	FE_4
Description	Any front-end must be in the condition to forward to the DCD all those requests referring to information that can be effectively published.
Rationale	The external service providers must have access only to a specific set of information.
Type	Functional
Priority	**M**

Table 131: Requirement FE_4 (requests forwarding service).

	Client requests & security management
ID	FE_5
Description	Any front-end must process the different clients requests independently from the client's identity and by availing of all available techniques in order to prevent the improper use of resources and any malicious attacks (e.g. denial of service).
Rationale	The front-ends must guarantee a secure and equal level of service to all external clients.
Type	Non-functional
Priority	**M**

Table 132: Requirement FE_5 (client requests & security management).

	Authentication capability
ID	FE_6
Description	Any front-end must be able to authenticate itself with the DCD.
Rationale	This requirement guarantees that the DCD is contacted by a reliable front-end entity and not by a malicious one.
Type	Non-functional
Priority	**M**

Table 133: Requirement FE_6 (authentication capability).

	Interaction with external clients
ID	FE_7
Description	Any front-end must expose a standard interface and use well defined and documented protocols to interact with the end-user clients.
Rationale	The use of standard or well defined and documented protocols is a way to enable the multiplication of external services.

Type	Non-functional (interface)
Priority	**M**

Table 134: Requirement FE_7 (interaction with external clients).

	Requests load management
ID	FE_8
Description	Any front-end must be designed in a way that it can be easily scaled as a function of the amount of incoming requests.
Rationale	It must be avoided the situation of impossibility to properly handle all the incoming requests from the end-users clients.
Type	Non-functional
Priority	**M**

Table 135: Requirement FE_8 (requests load management).

Variable Message Signs front-end

This front-end is in charge of directly managing the communication with the central system controlling the network of VMSs. The requirements defined for CLEAN-ROADS address in particular the type of information messages that can come from the RWIS.

	Information type
ID	VMSFE_1
Description	The variable message signs front-end must be in the condition to handle messages dealing with the following reference information categories: • **road surface conditions**; • **road weather conditions and events**.
Rationale	The RWIS covers only the publication of messages that deal with the status of the road infrastructure and the meteorological conditions which are relevant for the transportation network; other type of messages must be handled by components which are outside the CLEAN-ROADS system.
Type	Functional
Priority	**M**

Table 136: Requirement VMSFE_1 (information type).

	External client type
ID	VMSFE_1
Description	The variable message signs front-end must establish connections only with the central system managing the network of VMSs.
Rationale	This architecture choice guarantees the maximum scalability and interoperability opportunities; in fact this external system can then receive in input further pre-coded messages produced by other systems such as the CLEAN-ROADS one..
Type	Functional
Priority	**M**

Table 137: Requirement VMSFE_2 (external client type).

IP channels front-end

The IP- and the broadcast channels front-end are the end-point of the CLEAN-ROADS architecture which are in charge to deliver real-time information concerning the road weather conditions in the monitored road network. The front-ends are specificed so that it is possible to specifically address the different information formatting and organization needs of distribution channels relying on broadcast media or IP-based transport network. The following set of requirements apply for both front-ends.

	Data and information type
ID	IPFE_1
Description	The IP channels front-end must be in the condition to access to all type of generated data and information that the public authorities consider that are worth to be released, and where appropriate that have been previously validated by the authorized users of the GUI.
Rationale	Giving access to the maximum amount of information available in the MDSS will increase the exploitation opportunities of the entire MDSS in particular in the direction of advanced services for the local travelers.
Type	Functional
Priority	**M**

Table 138: Requirement IPFE_1 (data and information type).

	On-demand and periodic requests
ID	IPFE_2
Description	The IP channels front-end must be able to manage both on-demand and periodic requests coming from external clients.
Rationale	External clients can follow different logics for accessing the available data and information; the front-end must be designed in order to support both approaches.
Type	Functional
Priority	**M**

Table 139: Requirement IPFE_2 (on-demand and periodic requests).

	Standard communication protocols and interfaces
ID	IPFE_3
Description	The IP channels front-end must format and deliver the published data and information by using well-defined interfaces (i.e. web-services) and supporting standard web communication languages and reference standards used in the real-time traffic information domain (e.g. DATEX II, TPEG, etc.).
Rationale	The access to the published data and information must not be privileged and must designed in a way to maximize interoperability.
Type	Non-functional (interface)
Priority	**M**

Table 140: Requirement IPFE_3 (standard communication protocols and interfaces).

	Open data distribution licenses
ID	IPFE_4
Description	The release of data and information must be done according to a well-defined open data license.
Rationale	Licenses are needed in order to properly define the correct modalities of use of the published data and information.
Type	Non-functional
Priority	**M**

Table 141: Requirement IPFE_4 (open data distribution licenses).

Broadcast channels front-end

	Broadcast channels front-end
ID	BFE_1
Description	The broadcast channels front-end must be in the condition to handle only a specific set of information which is suitable for the distribution over a broadcast channel. It must cover “fresh” information only related to the current or predicted road weather situation and not directly consider historical data.
Rationale	Broadcast channels are suited to deliver few contents but that can immediately provide to a large part of the population an indication of the conditions of the road transportation network.

Type	Functional
Priority	**M**

Table 142: Requirement BFE_1 (broadcast channels front-end).

	Periodic requests
ID	BFE_2
Description	The broadcast channels front-end must be able to make available the updated information on a periodic basis.
Rationale	In the broadcast scenario, the periodic approach is the most appropriate one.
Type	Functional
Priority	**M**

Table 143: Requirement BFE_2 (periodic requests).

	Standard communication protocols and interfaces
ID	BFE_3
Description	The broadcast channels front-end must format and deliver the published information by using well-defined interfaces (i.e. web-services) and supporting standard web communication languages and reference standards used in the real-time traffic information domain (e.g. DATEX II, TPEG, etc.). The front-end must be independent from the broadcast communication technology uses by the service provider, which can be analog (e.g. FM) or digital (DVB, DAB) .
Rationale	The access to the published information must not be privileged and must designed in a way to maximize interoperability and in order to avoid dependencies from the broadcast communication technologies.
Type	Non-functional (interface)
Priority	**M**

Table 144: Requirement BFE_3 (standard communication protocols and interfaces).

Conclusions

This deliverable has presented the overall work of requirements analysis carried out in the scope of preparatory action A2. Based on the study of user needs and local inefficiencies, which have strongly availed of the relevant work done in other project actions (i.e. A1 and C1), it has been possible to identify eight different reference use cases, five applied to the winter road treatment activities carried out by road operators and three covering the behavior of local travelers. Based on a joint assessment work with task A2.2, which has evaluated the state-of-art of RWIS technologies and initiatives all around the world, it has been possible to consolidate a detailed reference system architecture of the CLEAN-ROADS system, and to define for each of the system components a set of functional and non-functional that will be useful to guide the design, implementation and integration activities covered by the Action Bundle B.

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