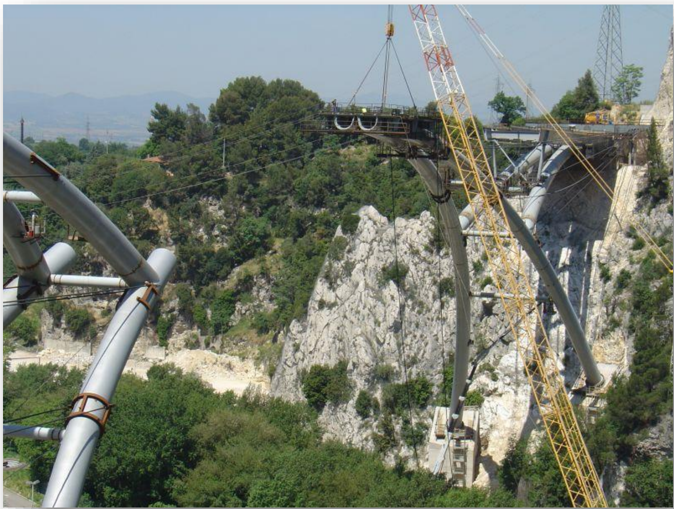
European Association of Remote Sensing Companies

Sentinels Benefits Study (SeBS)

A Case Study

Highways Management in Italy

May 2022



Client:	ESA
Client Representative:	Alessandra Tassa
Date of Delivery:	May 2022
Version:	
Author(s):	Geoff Sawyer (EARSC)
Supported by:	Nikolay Khabarov (IIASA)
Reviewed by:	Alessandra Tassa (ESA)

Version	Date	Comment
Draft	May 2020	First Draft
Final (first version)	August 2020	To be reviewed by ANAS
2.1draft (second version)	January 2022	Updated with new information from ANAS and others including for the Palizzi project. Updated to include considerations of climate change and views from civil protection.
Final version	May 2022	

For more information contact:

- **EARSC: info@earsc.org**
- **ESA: Alessandra.Tassa@esa.int**

Funded by the EU and ESA - ESA Contract Number: 4000119743/17/I-SBo.

Table of Contents

Table of Figures

Table of Tables

Setting the Scene

Elena was waiting in front of the ANAS Palermo office on Via Alcide de Gaspari. Her husband Sergio should arrive to drive her home. After a long, hot and tiresome day in the office, Elena was ready to relax with a glass of cool, white wine but Sergio was late.

When he arrived about 30 minutes after the time arranged, Elena climbed into the car and asked him if his delay was due to the roadworks on the SS624? No, he said there had been an accident, he had avoided the SS624 knowing that there could be delays due to the works.

"Those should be finished now," said Elena. "We had some problems with the project due to the late delivery of some drainage pipes. The contractors are responsible and are working long hours to finish their work."

"Fortunately, the road around Strasatto was open," said Sergio, "otherwise I would have been delayed by even more." Elena, smiled saying, "then you were certainly lucky! Those works could have been a major problem. One of the viaduct pillars started to sink as we worked on the carriageway. We are using a new technique to monitor our works which can detect when this happens. It is called InSAR and it uses data coming from satellites which are part of the European Copernicus project. I do not know how a satellite, flying 700km over our heads, can detect when the ground has moved just a few millimetres. But I do know that it saved us at least 6 weeks on the project. We were about to work on the next pillar, and we were able to agree with our contractor to change the foundations to avoid more problems. They were able to change the carriageway mounting to absorb further movement – more than had originally been specified."

"So, my arriving only 30 minutes late is due to the Sentinel satellite," laughed Sergio, "it is not just Galileo that can help me navigate more effectively! Great for our European technology – and thanks to our space agencies for making it so accurate"

"Yes indeed," said Elena as they pulled up in front of their house. "Now, please find two glasses and open a bottle of Carricante." It was their favourite white, coming from the small Vivera vineyard on the northern slopes of Mount Etna. "Let's drink a toast to Copernicus."

Setting the Scene provides a short anecdotal introduction to each case. This story is entirely imaginary, although realistic based on our knowledge gained through the case interviews. The places are real, although the characters, the conversation and the situation are entirely fictional.

Executive Summary

The Italian Roads Authority, ANAS[1] is responsible for a large part of the highway system in Italy overseeing a budget running at €4-5b each year to operate about 1,300 km of state motorways and about 32,000 km of roads in total, including about 2,100 tunnels and about 16,000 bridges. But this infrastructure can be vulnerable when the ground is unstable and, knowing where the ground surface is moving can help considerably to avoid problems. Italy suffers from many landslides; over 620,000 have been recorded on Italian territory. The earlier the potential slip can be identified the more the risk may be reduced in the planning, design, construction, and maintenance phases of roads.

Recently, a ground motion service based on Satellite technology using data from Europe's Sentinel 1 satellites, is being used by ANAS to help detect and monitor unstable ground. Time and money saved through avoiding re-engineering works or delays to projects are considered to lead to economic benefits of between €9m to €14m per annum.

Traditionally, the ability of roads authorities like ANAS to take account of ground instability in their work has been relatively limited. Measuring vertical ground movement is not easy. Alternative methods are either more expensive or less accurate than using the satellite-based technique InSAR to detect and measure where the ground surface has risen (heave) or fallen (subsidence) i.e. vertical motion. The recently launched Synthetic Aperture Radar (SAR) carried on Sentinel-1 allows large-scale maps to be generated showing precise movements at ground points only meters apart and with movements of a few millimeters. It has the potential to transform roads construction by significantly reducing the risk of engineering failures.

As the country-wide, InSAR maps have become available, so ANAS has started using them to support activities in several ways. We identify 5 projects under ANAS responsibility, and one other, which either do, or potentially can, illustrate the value that InSAR can offer. This report describes each of these examples and the impact of being able to detect and measure ground movement.

- Near Quadri, a small town in the central Apennines, historical data has been used during the road planning to understand which route would be the least vulnerable to movements.
- In Basilicata, works linked to a bridge were found to be causing movement deep underground which could be detected on the surface helping to understand what remedial measures were necessary.
- In Lazio, difficulties were encountered with a road design which could have been identified earlier and avoided had satellite data been used (which in this case it was not).
- In La Spezia near Genova, construction of a tunnel was stopped whist the causes of ground movements are identified. A redesign of the project will involve some re-routing, new

[1] ANAS Spa - *Azienda Nazionale Autonoma delle Strade (this is the old denomination of the Company)*- is a joint stock company, since 1st January 2018 part of the Ferrovie dello Stato Group. It is currently the concessionaire of the road and motorway network of national interest, which it has been managing since 1928.

tunnel works and significant additional cost which may have been avoided had the technology been available through earlier surveys. A satellite survey was carried out but has been of limited use due to the very low number of permanent scatterers in the area.

- Near Genova, a rain-triggered landslide damaged a motorway bridge (not managed by Anas spa) causing partial closure of the **A6 Torino-Savona (Autostrade per l'Italia)** for several weeks.
- In Palizzi, a tunnel has been driven through a hillside vulnerable to slipping. Corner reflectors have been deployed in the area which allow precise measurements to be made over a period of time and an accurate picture to be developed of where the road and tunnel construction, after a long stop of the jobsite, may be interested by ground movements.

Note that the cause of the ground movement is immaterial and may be caused by a natural geological condition of the area, by fault - leading to a local vulnerability, by the engineering works themselves, by excess rainfall and flooding, or movement triggered by seismic activity.

The current report looks at the benefits derived from the use of InSAR in ANAS activities linked to management of national roads. In analysing the benefits, the limited results from the 5 identified projects are estimated and then projected across Italy. Through this process, we arrive at the aforementioned overall, economic benefit. Looking at this along the value-chain – which lies at the heart of our methodology – we find that the benefits are largely associated with ANAS ie the planners and engineers designing and building the roads and the citizens who benefit through reduced road closure time and consequently less disruption to travel.

But the use of InSAR for roads management has other benefits as well as economic ones. The ability to measure movement can lead to a better understanding of vulnerable areas and to change regulations linked to construction as a result. Planners can avoid authorizing construction in these areas. Knowing when a movement took place can go a long way to helping understand the cause and, if necessary, attribute liability. Knowing the speed at which a point on the ground is sinking or rising can even help engineering works as well as improve the understanding of risk.

As a result of these experiences, ANAS has decided to introduce the use of InSAR mapping into future engineering tenders. Given the unique capability which the technology can offer, this is likely to lead to a significant increase in its use in the future.

The innovation associated with this new product and its overall potential has led to the service provider branding the service as Rheticus[2]. The possibilities it opens up across many sectors and applications, are also significant but are not included in this analysis.

[2] Georg Joachim Rheticus was the only pupil of Copernicus, the Polish/German astronomer, after whom the European Earth Observation system has been named.

1 Introduction& Scope

1.1 The Context of the Study

The analysis of the case study *'Highways Management in Italy"* is carried out in the context of the 'The Sentinel Economic Benefits Study' (SeBS). This 4-year study is looking to develop cases showing how EO-derived products based on data generated by one or more Sentinel satellites deliver value to society and citizens. The Sentinel satellites form a crucial part of EU's Copernicus Programme, providing space-based observations on a full, free and open basis. Data coming from the Sentinels – together with other data collected by contributing missions and ground, sea or airborne instruments – is used to support key economic or societal areas such as agriculture, insurance, disaster management, climate change monitoring, etc. Sentinel data are thus a key component of the Copernicus Services, and a crucial source used by companies to deliver products and services helping different users across the Globe.

1.2 What is the Case all about?

Italy is a beautiful country with wonderful, natural landscapes, friendly people and of course very tempting food. It has a well-developed road system, arguably the oldest in the world, which started in the times of the roman empire. An empire that has also created many important, ancient, archaeological sites and many old towns and cities ill-adapted to modern transport systems. Maybe as a consequence, in 1924 Italy was the first country in the world to construct a "motorway" ie a two way, separated highway reserved for motor vehicles[3] and often referred to as a *controlled-access highway*, which today form the backbone of rapid communications and transportation infrastructure in all developed countries.

Now, Italy has an extensive and comprehensive road network connecting towns and cities in the country but also connecting with neighboring countries as part of the Trans European Network or TREN. But Italy, whilst being an old hand for building road systems, is a young country in terms of its geology. The Apennines, which run the length of the country is where the African and European tectonic plates meet. Periodically, they move dramatically causing a major earthquake with consequent destruction. But it is the continuous, sustained but small movements which may cause less significant but still potentially catastrophic shifts of the land surface. The regular movement and young geology mean that large parts of the country are unstable; not having experienced the millennia necessary to construct a stable terrain. In consequence, construction works are at risk from the movement of the ground resulting in landslides.

The risks to the road network are obvious but can be mitigated by knowing where movement is taking place and how large this is. Data from radar satellites such as Sentinel 1 can be used to monitor the ground and the movement - whether this is as a result of seismic, heavy rain, or man-made activity. This technology is now being introduced into ANAS - *Azienda Nazionale Autonoma*

[3] https://en.wikipedia.org/wiki/Autostrade_of_Italy

delle Strade - the agency responsible for the management of the Italian road network, as part of their procurement and monitoring process in situations where the risk is considered to be elevated.

This case is about how regularly updated maps showing the movement of the land can be used by organizations such as ANAS and other road operators, to improve their management of the road network. Such maps can cover wide areas, offer quite closely-spaced measurement points on the ground, and show very precise movements of a few mm. In some cases, corner reflectors may be deployed at the site to enhance the measurements. Maps can also be developed to show the impact over time and if movements are accelerating.

Since ANAS' responsibility concerns the national roads and not urban transport infrastructure, the case is focused on rural, or non-urban areas. It covers examples during the planning, design, construction, and operations phases of road-building projects. The technology is new and has been used in very few projects to date, but awareness of its potential is growing in ANAS as it gets introduced into more and more projects. In our analysis, we take the proven examples and extrapolate these to show how it may be able to reduce financial risk to the agency and the contractors working under their supervision. In the end, improved management of the road network benefits the movement of goods and people which affects every part of the Italian economy and is vitally important for the effective functioning of the emergency services and their ability to get quickly to the scene of accidents and natural disasters.

1.3 How Does this Case Relate to Others?

When we started, this was the first case which we have investigated looking at the management of road infrastructure but the second one using Sentinel-1 to measure ground movement. The earlier case looking at pipeline management in the Netherlands[4] was also based on this application using Synthetic Aperture Radar (SAR). Since starting it, we have also analysed a similar story in Norway concerning roads management and a very different application for monitoring underground aquifers in Spain. There are many possible applications of this technique and consequent products and services.

The case is also based on events or projects rather than a continuous operational process. As we look at more cases, they are dividing into these two categories:

- Operational such as shipping through icy waters, or agriculture production c.f. farming.
- Event or project-based such as with flooding or transport infrastructure management.

The second category is harder to address economically, than the first, since it relies on developing several examples which may not each be fully representative. As a result, the assumptions which are made for the analysis are less precise and broader ranging.

[4] Pipeline Infrastructure Monitoring in the Netherlands, Sawyer & DeVries, May 2016

In the case of highways management in Italy, the focus is on events either during the planning, design or construction phases, or road failures during the maintenance phase. We have identified a number of relevant events and use these as the basis for our analysis.

1.4 More About the Study

Each case study analysed in SEBS focuses on products and services that use data coming from Sentinel satellites and assessing the impact of that product or service throughout the value chain. The starting point is the primary user of the satellite data, followed by a step-by-step analysis whereby the operations of beneficiaries in each subsequent link of the value chain are analysed, all the way down to citizens and society.

In this process, the main aim is to understand and demonstrate the value which is generated using satellite-based Earth Observations (EO) and particularly the data coming from the Copernicus Sentinel satellites. Each case study thus underlines the causal relationship between the use of Copernicus Sentinel satellite data and benefits resulting from their use, including increased productivity, more efficient and environmentally friendly operations, economic gains and improved quality of life, among others. The evaluated and demonstrated benefits can be used by:

- **Decision-makers**: Having access to a portfolio of concrete cases where the benefits from the operational use of Sentinel data in decision making are clearly articulated, helps decision-makers, not only to justify future investments but also to direct them towards areas that most matter in their country or organization.
- **Users:** Moving beyond a vague idea of how EO services can support more effective operations requires a concrete understanding of the benefits they can actually bring in similar cases. In this regard, it is both numbers and stories that can resonate with users and attract them to explore further or deeper uses of EO in their operational activities.
- **Service providers:** Solid argumentation around the economic and environmental benefits stemming from the use of EO, coupled with powerful storytelling, can become an effective marketing tool for service providers seeking to promote their solutions and for EARSC to promote the sector.

In the framework of this project, up to 20 case studies will be developed with reports to be published on each one. The study has started in March 2017 and will end in mid-2023.

1.5 Acknowledgements

Producing this case study report would have been impossible without the invaluable insights and kind assistance of key stakeholders. They helped us navigate across the various aspects of road management from the perspective of a national agency; in particular thanks to Sergio, to Serena and to Flavio who introduced us to a number of the experts we have consulted. We wish to thank the following persons for their time spent talking with us to develop the case.

- Sergio Samarelli – Planetek Italia
- Serena Majetta - ANAS
- Flavio Capozucca - ANAS
- Ilaria Coppa – ANAS
- Alessandro Bonella ANAS
- Emiliano Loi – ANAS
- Maurizio Martino – ANAS
- Cristina Ferrari – ANAS
- Angelo Dandini - ANAS
- Maria Marsella – Survey Labs, Rome.
- Georgia Giardini – University of Bath / Technical University of Delft
- Chiara Cagnazzo – Copernicus Climate Change Service, European Centre for Medium-Range Weather Forecasts (ECMWF).
- Carlo Buontempo - Copernicus Climate Change Service, European Centre for Medium-Range Weather Forecasts (ECMWF).
- Alessandro Borgese, Department for Civil Protection, Italy
- Valeria Silvestri, Department for Civil Protection, Italy
- Paola Pagliara, Department for Civil Protection, Italy.
- Salvatore Stramondo, Head of National earthquake Observatory,

2 Roads Management in Italy

In this chapter, we look at the way roads in Italy are constructed and managed. We look at the issues faced by ANAS the state-owned company which lies at the heart of this case. The common thread is ground-movement and the way this impacts the roads being planned, designed, constructed, and managed.

2.1 Roads in Italy

Road networks are a vital part of a country's' national infrastructure and it is fitting that this case, concerning the management of highways, is set in Italy. The first paved road is thought to have been developed in Macedonia in 4000BC, but a road network was first developed by the Romans when paved roads were constructed to allow their army to move more rapidly. The network originated in what is now Italy ("all roads lead to Rome") and extended to the limits of the Roman empire.

The road building tradition continued and, in 1924, Italy was the first country in the world to build a motorway[5] and now has one of the most developed road networks in the world with 6,800km of autostrade out of a total of 256,000km of roads across the country (see Table 2-1). Building and managing this network is a challenge.

Type of Road	Km.
Motorways (Autostrade)	6,751
State / national Roads	19,920
Secondary or regional roads	154,948
Other roads (non-urban)	74,420
Total	256,039

Table 2-1: Road Network Statistics for Italy[6]

Roads are a vital part of the transportation network and recognized parts of Critical Infrastructure (see 2.5.2).In Europe, nearly 50% of the goods transported in terms of tonnes-km are by road see Figure 2-1. Considering only inland transportation, this rises to 72.8% showing the critical importance of the highway network to the economy. We could not find figures for Italy (Eurostat collects this data but it is absent for Italy) but, in the US, the national highway system (NHS) which are equivalent to the autostrade in Italy, comprises just 4% of the total roads but carries 40% of traffic and 70% of freight demonstrating the importance of this infrastructure to the overall economy. Whilst the numbers will differ for a more densely populated country, as in Italy, the principle remains and investment in the infrastructure is a vital need for economic development.

[5] Now part of the A8 connecting Milan to Varese.

[6] European Road Foundation; Road Statistics.

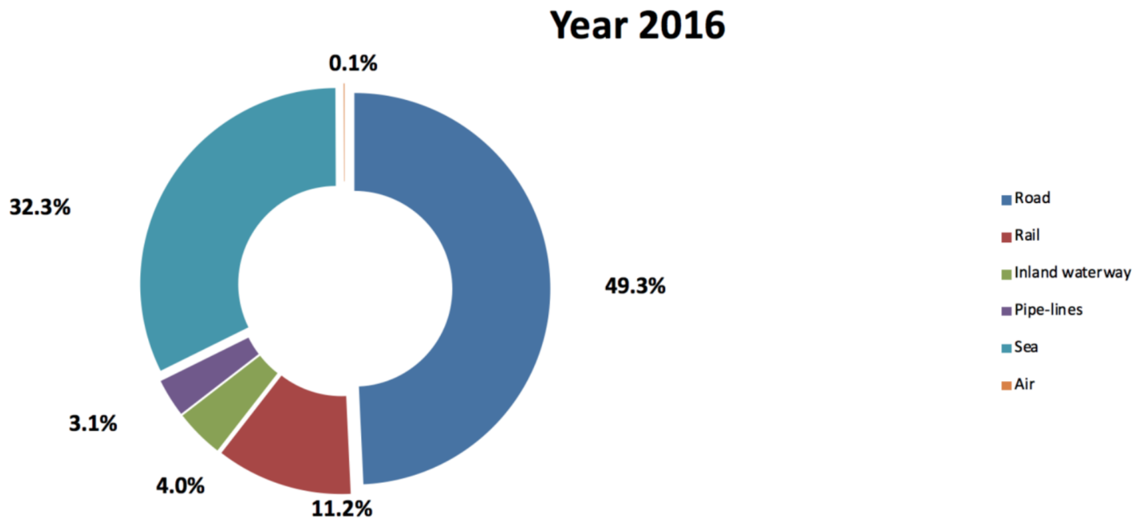


Figure 2-1: Goods transport comparison of transportation modes in the EU (tonnes-km)[7].

This infrastructure is vulnerable to ground movement and the geological risk is high in large parts of the Italian territory. Movement of the ground can be caused by several factors but in Italy, the primary cause are landslips caused by slope instability driven by the young geological formations and active dynamics. In recent years, increased rainfall and reduced maintenance of slopes has exacerbated the problem.

In Italy, the overall responsibility to manage the road infrastructure is assigned to the National Autonomous Roads Corporation (Azienda Nazionale Autonoma delle Strade, ANAS), since 2018 a part of the Ferrovie dello Stato Group, which is the primary-user organization at the heart of this case.

ANAS works closely with both the national administration and the regional and local administrations. Whilst ANAS has overall responsibility for the national road network, within urban areas and for some rural roads, the responsibility is devolved to a local level. We see in Table 2-1 the 4 classification of roads and the level at which they are managed:

- Highways or motorways which are the major interconnecting roads of which the over 6000km in Italy are primarily toll roads. ANAS operates 1,300km directly with the rest operated by private companies such as SIAS and Atlantia.
- State roads which are mainly directly controlled by ANAS.
- Urban roads which make up the greater part of the network and which are controlled by the relevant urban authority.
- Small, country roads which are controlled by the regional authority.

[7] European Road Federation: freight statistics (https://erf.be/statistics/freight-transport-2019/)

2.2 Causes of Ground Instability

Italy is a geologically young country with significant instability of the ground. Whilst the frequent earthquakes are well known and a strong reflection of this geology and are the cause of dramatic movements of the ground with a great deal of associated damage, landslides occur much more frequently and are the more frequent cause of damage.

2.2.1 Landslides

Landslides, or landslips, may be triggered by a seismic event but much more usually result from heavy rains or simply by incremental movement with time. They can cause significant damage as can be seen for a recent landslide in November 2019, provoked by heavy rain, which damaged the A6 motorway near Genova, closing one side of the carriageway for several days see (Figure 2-2).

Figure 2-2: Landslide provokes bridge collapse near Savona in N Italy

Over the years, a picture has been constructed by IFFI, a catalogue elaborated by the Italian Geological Survey, showing the history of landslides throughout the country. Figure **2-3** shows the 620,000 landslides which have been recorded with the most densely concentrations lying along the Apennines and the Southern Alps.

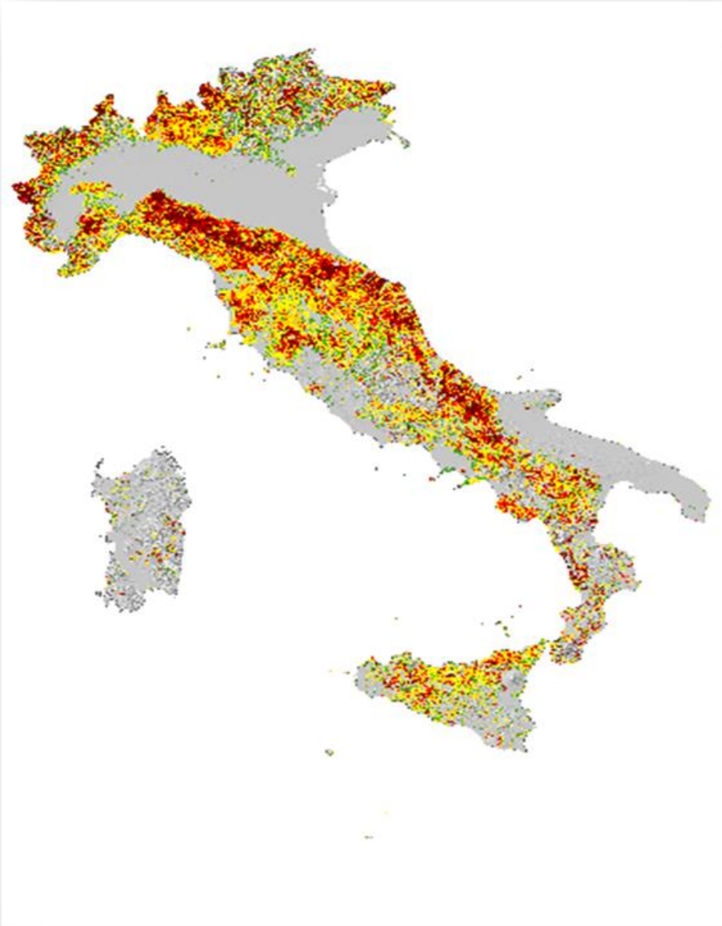


Figure 2-3: Map showing history of Landslides in Italy.

The impact of landslides on the road network[8] has been studied within an FP7 project LAMPRE[9]. "*In Italy, geohydrological hazards, including landslides, cause serious economic damage and represent a severe threat to the population (Salvati et al. 2014). In this country, rich information exists on landslides, their physical characteristics and consequences, while little is known on their economic impact.*"

Using the statistics from the project, Figure 2-4 is constructed to show the incidence of landslides having an impact on the road network in 2016, when 18 such events have been reported.

[8]Impact of event landslides on road networks: a statistical analysis of two Italian case studies. Marco Donnini et al. Open web publication. https://www.researchgate.net/publication/317752987

[9] LAMPRE: Landslide modelling and tools for vulnerability assessment, Preparedness and Recovery Management.

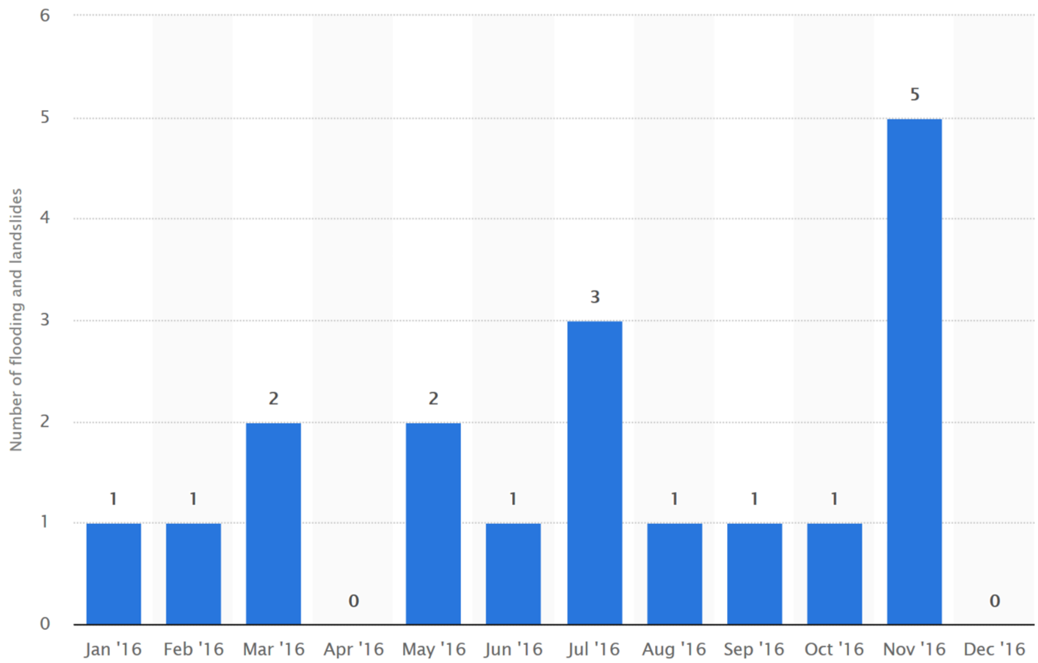


Figure 2-4: Flooding leading to Landslides in Italy in 2016

To understand the economic impact of landslides disrupting road networks, the LAMPRE team focused on specific events to draw some lessons. Two, rainfall-induced, landslide events in Central and Southern Italy were examined to look atthe physical and economic damage and to obtain road restoration cost statistics. Separating the impact of the road closures caused by geological events from those caused by flooding led to the conclusion that the cost of geohydrological damage to the road network across Italy is around €900m per annum. Furthermore, this may become higher cause of climate change, we don't know the "acceleration entity" of this process, we shall discuss in chapter 2.2.4.

In conclusion, each year, Italy is suffering from many landslides and ground movements which can cause damage to the road network. Some of these are abrupt failures where no sign may be evident beforehand. Some take place over a longer period, and some may even be provoked by construction work itself. Knowledge of the vulnerable areas can help engineers design better structures. Knowing where the ground is moving and how fast can be a great aid to road designers and engineers throughout the development cycle, as we shall see.

2.2.2 Seismic Movement:

Highlighted by the relatively frequent destructive earthquakes, the instability extends across the country – see Figure2-2 - and presents a major issue for the construction and management of the road infrastructure in Italy.

The Apennines, which run the length of the country, is the mountain range where the African and European tectonic plates meet bringing two challenges:

1. Mountainous terrain with deep valleys demanding tortuous routes, viaducts and many bridges and tunnels,
2. Frequent ground tremors and occasional severe earthquakes so threatening and disturbing infrastructure.

Dealing with the consequences of the geological instability costs Italy a lot. High-profile earthquakes cause awful destruction and loss of life. Fortunately, these are much less frequent than the tremors and small-scale movements of the ground. But it is the latter which cause most disruption to the road infrastructure. Mitigating the risk and consequential costs can be very beneficial to all Italy's road operators and users. Satellite imagery now provides the means to get more control over these risks.

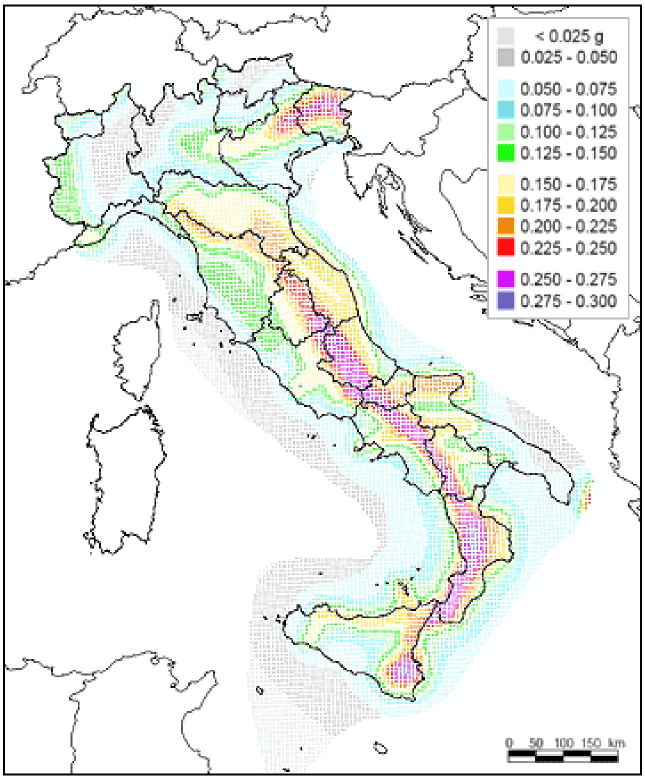


Figure 2-5: Map of seismic risk throughout Italy

Steep landscapes are also subject to destructive landslides and both these natural phenomena will be considered in this case study in respect to their impact on the road system.

Seismic shocks leading to movement of the ground gives rise to several problems throughout the lifecycle of the roads. The Italian Institute for Geophysics and Volcanology (INGV) monitors seismic activity and publishes reports and statistics; the most recent bulletin from their website being for mid-2019[10]. This shows that in the 2nd quarter of 2019, 5614 earth tremors were recorded of which 1,616 were of magnitude 1.5 or greater and 17 were of magnitude 3.5 or greater (see Figure 2-7).

Whilst only higher magnitude earthquakes of magnitude 5 or above, which cause visible damage or danger to people, are generally widely reported, smaller quakes and tremors are a greater cause of damage to roads. As we can see from data from INGV, figures for the whole of 2019, (see Figure 2-7) show only 1 earthquake of magnitude 5 occurred, 32 of magnitude 4 or greater but a total of 16,966 of all magnitudes were registered.

Figure 2-8 shows the location of the 32 earthquakes of magnitude 4 or higher during 2019. No part of Italy is un-affected.

[10]http://terremoti.ingv.it/en/bsi?id=10.13127/BSI/201902

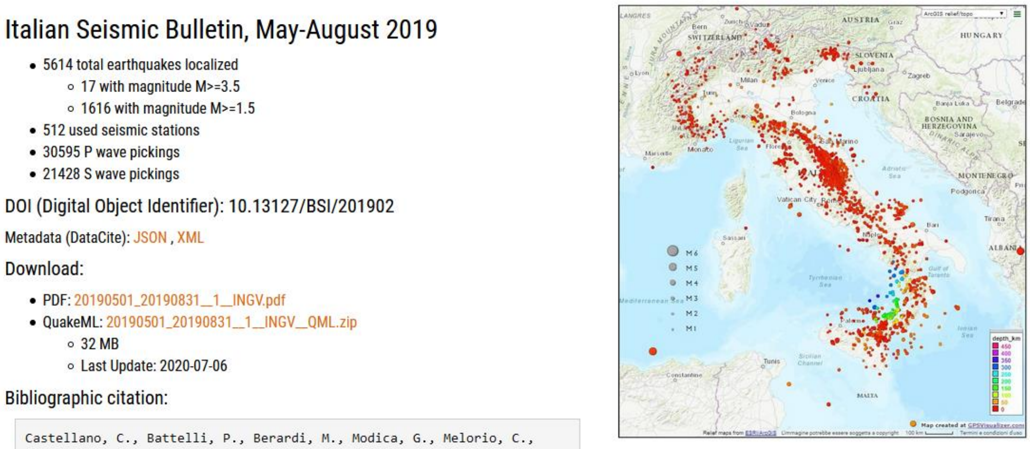


Figure 2-6: Earthquake bulletin for May-August 2019

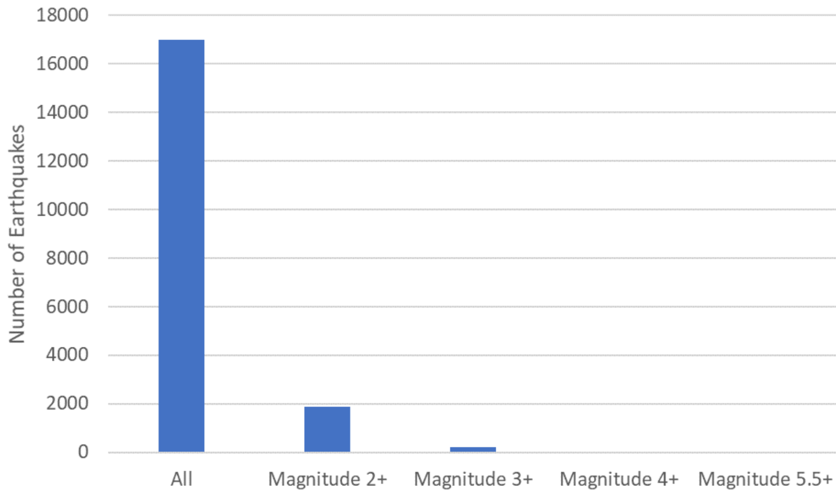


Figure 2-7: Earthquakes registered in Italy by INGV in 2019 (source INGV[11])

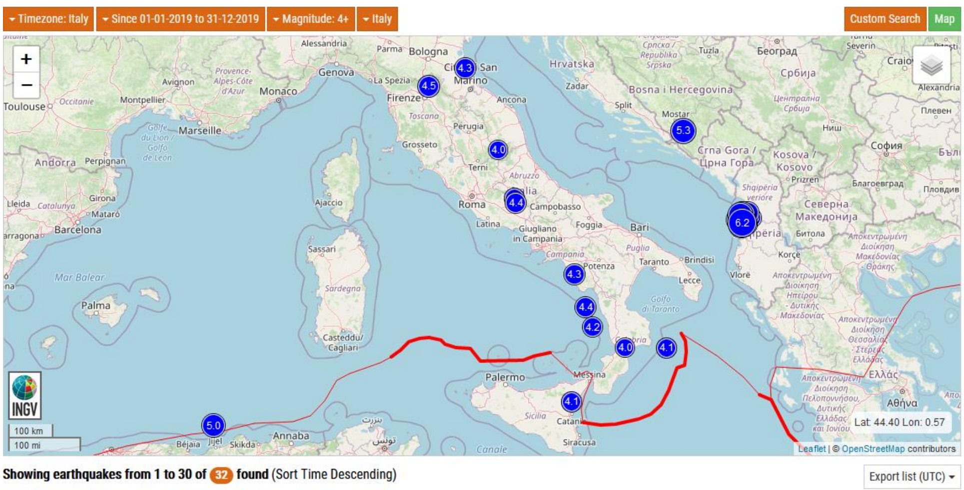


Figure 2-8: Magnitude 4+ earthquakes registered during 2019.

[11]http://terremoti.ingv.it/en

2.2.3 Other causes

Movement of the ground can also result from other causes which are more rarely encountered in Italy – if at all.

- Underlying clay or sandy soils can also sink over time – as we saw in the case in the Netherlands[12]. Clay especially is prone to cycle through periods of damp and dry when it swells and shrinks so leading to ground movement. Sandy soils can be washed away by underground water flows so causing the surface to sink.
- Moraines which are the result of glaciers pushing material under their weight which is then deposited often where the glacier ends. We have found this cause in the case in Norway but have not learned of instances in Italy where this is an issue.
- Water extraction can cause underground aquifers to drop and lead to movement at the surface – as we have seen in a case in Spain.
- Engineering works such as piling, deep drilling or earth movement can all trigger vertical movement at the surface.

How does this risk of ground movement play out as new roads are conceived and built?

2.3 The Development Cycle of Roads

Where road and highway networks are already well-developed, investment is focused on improving existing links rather than new road construction – although this may often mean replacing a part of an existing road i.e. as a bypass to a town or a new bridge or tunnel to shorten the route. This can also mean the construction of new state roads and highways where the traffic is denser.

Projects, whether new roads or road improvements are decided over a multi-year cycle and involve negotiation between the Italian state, local administrators and other stakeholders. The process is managed by ANAS. ANAS keeps a map of locations across the country where environmental issues (noise, pollution etc.) and/or traffic congestion or accidents could merit from new road development. Typically, there may be 4 hotspots per region. These are reviewed by a planning group in ANAS and subject to the authorised budget, one or more is selected for deeper analysis on the impact of carrying out the road works. In the end, it is a joint state/region decision as to which projects move forward.

Review and decision of the projects is at this stage based on an estimated cost for each project. Once a project has been decided, it moves into a more detailed planning phase, then onto the construction phase and finally into operations. At each stage, the stakeholders are consulted regarding the overall plan.

There are four main parts to the development process;

1. Planning phase
2. Design phase

---

[12] Pipeline infrastructure monitoring in the Netherlands. Sawyer & Devries, May 2016.

3. Construction phase
4. Operations (and maintenance) phase

Each of these has many activities associated to them, but the main characteristics of each are described as follows:

a. Planning Phase:

   In the initial planning period, when the priorities are being established, surveying of the area is limited due to cost and is undertaken mainly to understand the geological characteristics of a chosen route – which is a key factor, driving the costs. If the route changes, additional surveys would need to be carried out, so until the project is decided, decisions are based on the underlying geology. Up until now, the vulnerability of the route to ground movement has been assessed based on historical, expert information coming from the geological survey, and no systematic surveys have been undertaken to plan the route to avoid unstable areas.

b. Design phase:

   In current practice, once the project is decided, a more detailed design process will confirm the route, the construction techniques to follow and of course the costs. A more detailed route survey will be performed but no specific study is usually made to assess the vulnerability of the route to ground movements, largely due to the cost of such surveys and the absence of site-specific, historical data.

   For the first time, the use of satellite data offers the possibility to assess the risk of ground movement within the planning and design processes. If historical satellite data ie archived imagery is available it allows an assessment to be provided based on past movements which can provide a good guide to route selection. Currently, country-wide maps showing ground movement are being developed which will ensure all routes may be examined in the future. Knowing that a part of the route is vulnerable to ground movement can change significantly the future risk to the project arising from escalating costs due to unsuitable route selection or design and construction methods.

c. Construction phase:

   Once the project is planned, decided and confirmed, the construction phase starts. During this phase, the risk is that previously undetected ground movements show up during construction forcing a costly revision to the project or even that movements are triggered by the construction work.If this directly affects the construction, it can (and has) lead to disputes between the authority (ANAS/local authority) and the engineering contractors. Detecting the movement and when it occurred can be critical evidence when resolving such disputes.

d. Operation and Maintenance.

   Once the construction is completed, responsibility is passed to the road operator - this may be ANAS, a private company or a public authority. Any ground movement now can lead to the need for remedial works with accompanying road closures or diversions and consequential costs to transport companies and the general public. The impact of transport disruption after the road is completed is even more than before as traffic flow has adapted to the improved routing, fewer junctions, extra lane capacity, better road visibility or even just a better, faster, more comfortable surface.

Throughout these four phases, various decisions are being taken where knowledge of any movement of the ground may be important. Knowing where the ground is moving, by how much and how fast and even when the movement has occurred, can support the various players concerned with the road development. Previously almost impossible due to the high cost and technical difficulty, this is now changing as InSAR becomes available and especially as a history of InSAR maps can be built up. We'll look at alternatives later but let's consider what impact the movement has and what changes this can lead to. How might this help the development process?

2.4 Impacts of Ground Movement

Clearly, if the ground is moving for whatever reason, this means bad news for the roads. The impact varies enormously depending on the conditions and the cost implication depends strongly on the phase of work. The impacts differ according to the state and nature of the project; the earlier the instability is known about, the easier it is to introduce measures to reduce the impact – and the additional cost!.

As we discussed earlier, we can only understand this by looking at individual projects and, whilst we cannot generalise, we can use the projects as the basis for our analysis; 2 of these fall in the planning/design phases and 3 in the construction phase with 1 event happening in the operations/maintenance phase with an existing highway.

1. (planning phase): In Abruzzo (Quadri), a new road – the state road 652 "Fonde Valle Sangro" in the province of Chieti, is being constructed and satellite data including that from Sentinel 1 has been used to help in the planning phase of a project - and decisions have been taken as a result of using satellite data.

   Using satellite data on a regular basis will allow the detection of smaller ground movements and for potential risk to be assessed as part of the planning / design process. This benefit has been recognized and ANAS has included provision for a monitoring system to be established before construction starts where satellite measurements are included in the project plans.

2. (Construction phase): In Basilicata, the San Stefano highway work to construct a viaduct has been affected by terrain movement. Towers at one end of the viaduct have been found to be sinking. leading to a difference of opinion regarding the engineering works and the legal basis and responsibility of the construction company versus the roads authority.

   As a consequence, ANAS has made provision for a more systematic monitoring of sites during the construction period. For 5 recent projects, tendered by ANAS, satellite monitoring during the construction period has been included asa requirement.

3. (planning phase) In Lazio, a new part of the highway is being planned. No satellite data was used but, due to a suspected threat of movement, ANAS did commission some geomorphological surveys to help select the route. In the future, this would be replaced with less expensive, InSAR maps.

   In general, ground movement is not assessed during the planning phase. If the route changes, then no data is available for the new conditions. Hence, there is a strong trade-off between the cost of the survey, whether it will be finally useful and the risk of problems arising later.

   The use of InSAR satellite maps, which are much less costly can help ease the decision on whether to survey the route for ground movement risk or not and around 2 years ago it became a requirement to assess the risk of ground movement by conducting an appropriate survey where necessary.

4. (Construction phase): In Liguria at Carozzo (La Spezia) just outside Genoa, tunnelling work has been halted due to movement of an old landslide re-triggered by the works. No satellite data has been used as, once the slip was known, decisions were taken to change the construction method and avoid problems. Again, the pointer here is to improve knowledge of the terrain before work starts and to monitor what is happening as works are undertaken to reduce risk of especially technical, but also legal, problems later.
5. In Palizzi (construction phase), in the very south of mainland Italy in the region of Calabria, a new road - "S.S. 106 "JONICA" - is being constructed. The region is mountainous, and tunnels are required. The work has been stopped due to landslides, which seem to be unavoidable given the terrain, and planning has restarted to examine how to live with the instability. Corner reflectors are being deployed in order to measure more precisely the movement, to keep track of it over time and to understand the trend and risk. It is planned to maintain the corner reflectors for 4 or 5 years whilst the tunnelling takes place. Interferometric monitoring was planned and performed during the design phase (2018-19) integrated (2021), (pre-construction, eight months), which sees the installation of 18 Corner Reflectors. Monitoring will continue with the ongoing phase of the work (thirty-six months) and Post construction (twelve months).**Figure 2-9** shows the type of CR being installed for the construction of the southern carriageway.
6. (Operations / maintenance phase): near Savona between Genoa and Turin in November 2019, a landslide caused a motorway bridge to collapse (Figure 2-2). Heavy rain had infiltrated the steep slopes in the landscape near the pillars supporting the bridge. As a result, the land slipped and caused one of the pillars to collapse closing one side of the highway. The second part of the highway was undamaged and almost normal traffic resumed within 3 weeks of the disaster although the time to reconstruct the bridge is forecast at 4 to 6 months.

We discuss elsewhere how the use of InSAR is limited in its ability to detect landslides largely due to the time delays involved between measurements. However, regular observations of the embankment might have shown some slippage before the collapse occurred and, if signs were visible, could have precipitated some remedial action before the damage to the highway.

Figure 2-9: Corner reflector being installed at Palizzi.

Mitigation measures differ according to the nature of the problem and the phase of work. Knowing that there is a risk of ground movement may lead to increased protection being put in place during or even after construction works.

A greater risk and consequential cost may be faced by having to perform re-work due to movement encountered during or after construction. If the issue is identified earlier, a different design could be adopted to mitigate the risk. As in the La Spezia tunnel, the cost of remedial works is known. How much could have been saved if the problem had been recognized earlier? We shall return to this in chapter 5.

2.5 The Socio-environmental Context

Are there other societal factors of which we should be aware when considering the impacts on highways management? Two which we have been asked to include and consider are climate change and European legislation.

2.5.1 The Impact of Climate Change

The last few years has seen more extreme events such as flooding and fires with a significant impact on road infrastructure. Scientific opinion backed by a growing political and societal conviction that these damaging events are a consequence of climate change. What may be the potential impacts for road infrastructure management?

The World Road Association (PIARC) has published reports[13],[14] offering analysis, advice and tools for national highways authorities to define their strategy for dealing with the consequences of climate change. The US Environmental Protection Agency (EPA) is conducting a project on Climate Change Impacts and Risk Analysis (CIRA) which has produced views[15] on the impact of climate change on the transport infrastructure and a useful summary brochure[16]. Finally, the Highways Agency in England has published views[17] on the preparedness marking progress in their work. All of these take the view that the impact of extreme weather most notably heavy rainfall and floods will have a strong impact on roads largely due to geological instabilities.

The main issues identified in the reports are dealing with countries under different climatic conditions. However, some findings are drawn with respect to differing changes:

- Increase in storms can lead to flooding of the road surface, landslides and mudflows damaging the road surface and bridges / tunnels, soil erosion undermining the road and structures.
- Cyclones and severe storms can lead to the above impacts as well as possible overstressing of structures including gantries and road signs risking motorists,
- Low temperatures can lead to damage to the road surface, thermal movement in bridge joints, as well as a risk to electric controls and signaling,
- Low temperatures can lead to essentially the same risks as for high temperatures plus risk of fires obscuring visibility and obstructing passage.

Any of these may lead to disruption of the road network and increased maintenance and repair costs. Many of these risks concern movement of the ground surface meaning that satellite data can play a role in monitoring, detection and risk mitigation.

As the PIARC report recognizes, most road infrastructure is now built to last for 50 years or longer and understanding how future changes in climate might affect this infrastructure is important to protecting long term investments. Designers and engineers rely on historical records of climate when designing roads. However, due to climate change, historical climate data alone is no longer a reliable predictor of future impacts.

The framework developed by PIARC is intended to support roads authorities and decision makers to put in place a strategy for adaptation to the assessed risk. This starts with developing an understanding of the vulnerability in general terms before assessing the risk associated with specific assets. This requires an understanding of the likely climatic changes which will be experienced.

The European Centre for Medium-range Weather Forecasts (ECMWF) provides some general assessments (see Figure **2-10** as an example. In this case showing forecast soil erosion in 2050 compared to the present), for a range of parameters which are mainly at a national or regional level

13 Dealing with the effects of climate change on road pavements, 2012RO6EN.

14 International climate change adaptation framework for road infrastructure, 2015RO3EN.

15 Climate Action Benefits – Roads.

16 Roads: EPA/CIRA.

17 Highways England: Climate Adaptation Risk Assessment Progress Report 2016.

whereas road projects are by definition local in nature. Countries are producing climate impact scenarios (for instance in the UK[18]) whilst a transnational group of roads researchers has produced a Climate Projection Database for Roads – CliPDaR[19] - which identifies potential local impacts.

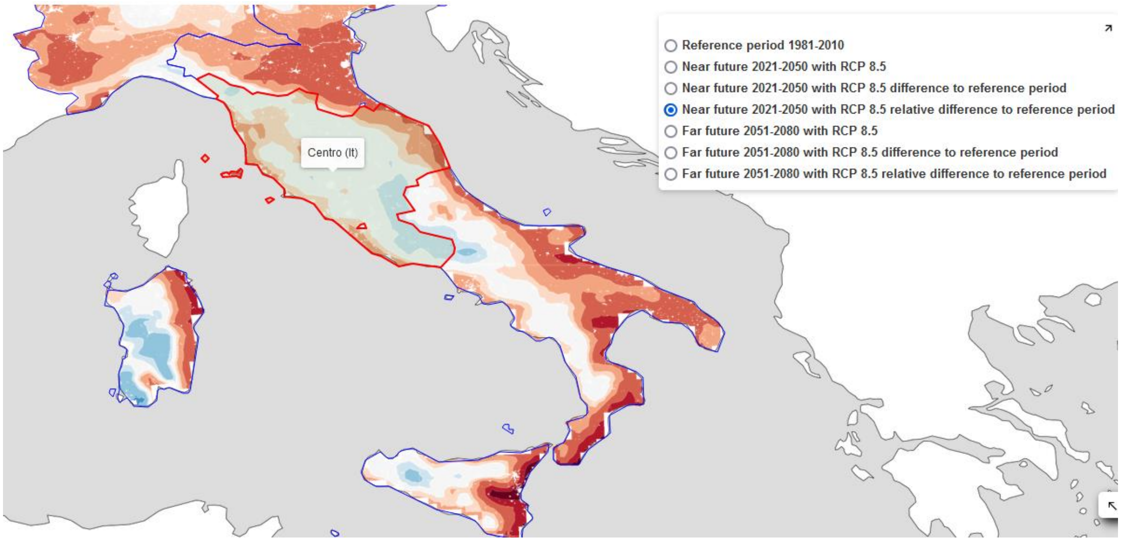


Figure 2-10: Soil erosion profile for 2050[20].

The ECMWF services are available through the Climate Data Store which has been developed a part of the Copernicus Climate Change service (3CS). Other forecasts include parameters for rainfall, fires, as well as the soil erosion. In addition, a study has been made into potential impacts of climate change on railways taking Spain as an example. This is due to be published shortly at the time of writing.

2.5.2 European Legislation for Critical Infrastructure Protection

An additional factor is that of protecting infrastructure against threats and damage due to natural disasters which is the responsibility of national governments. In recent years, a European dimension has emerged with the recognition that transport (and other) networks which connect countries in the European union, have importance beyond national borders. These Trans-European Networks are considered to be key to efficient logistics in the EU.

In 2006, the EC produced its first report into critical infrastructure driven by the fear of terrorist attacks. Despite these fears, the first directive became driven by other concerns and the goal to

[18]Climate change impact scenarios - GOV.UK (www.gov.uk)
[19]https://ui.adsabs.harvard.edu/abs/2013EGUGA..15.9810M/abstract
[20]Soil Erosion Explorer: https://cds.climate.copernicus.eu/cdsapp#!/software/app-soil-erosion-explorer-italy?tab=app

identify critical risks notwithstanding the source. The 2006 staff working document led a request from Council to propose legislation which led to the Council Directive 2008/114.

The directive established an EU-wide procedure for identifying and designating European critical infrastructures and a common approach to assess needs so as to improve protection from anthropogenic threats – both intentional and accidental – as well as natural disasters. As well as transport, energy networks were also addressed reflecting the origins of the European program for Trans-European Networks (TEN).

The outcome was reviewed in 2012 and again in 2017 concluding that the legislation had little impact and was now outdated with respect to increased threats. In this respect the security dimension was being recognised as more important as well as a growing competence for enhancing security at the European level.

Consequently, a new legislative proposal was presented by the EC in December 2020 which would increase the responsibility of Member States to establish strategic plans and operating procedures taking into account a broader number of threats including cyber threats and that coming from drones. A European parliament report[21] has highlighted a way forward.

2.5.3 Environmental Impacts on Highways.

Whilst knowledge of the ground stability is a key input into estimating the project cost, it has no real impact on the environmental impact of the built road, nor for the construction period. Hence, there are not considered to be any significant environmental benefits of using ground motion maps. The stability becomes one further factor to take into account when deciding routes to follow and may even help reduce impacts by reducing the risk and/or occurrence of road closures and subsequent congestion. But the direct environmental impact is considered to be low or negligible.

The construction of underground structures may have an impact on aquifers and water flows. Building a tunnel may divert water from one area to another with potential consequences for farmers and local citizens. Piling, where a column penetrates various sub-surface strata before reaching bedrock, may cross layers of clay and impermeable rocks, so allowing water to rise to the surface. This can distort the clay layers as well as cause subsidence as pressure is released. This is one of the most common causes of subsidence arising from infrastructure construction.

Although we have not come across any specific examples, works may sometimes be left uncompleted due to budgetary or planning difficulties. It is not impossible that becoming aware of instability, which could significantly lead to an increase of cost and a project abandonment, could be avoided by earlier knowledge of ground motion.

[21] European Parliamentary Research Service Author: Irmgard Anglmayer Ex-Post Evaluation Unit PE 662.604 – February 2021.

Can the use of InSAR lead to better regulations? Maybe linked to building works, selection of suitable sites and even the duty to inspect the infrastructure? In what ways can knowledge of the ground movement affect the decisions which are taken?

Finally, in addition to actual damage, ground movement can also cause structural instability to infrastructure which may lead to future damage through failure. This is a topic of particular sensitivity in Italy following the dramatic and tragic accident which arose as we prepared the first version of this report, when the Morandi bridge in Genoa, collapsed in August 2018, killing 43 people, injuring many more and destroying several houses underneath (see Figure 2-11).

Disruption to the local way of life was heavy. Through traffic faced a 40km detour around Genoa and local inhabitants were taking much longer driving to work, to schools, to shops each and every day. 600 inhabitants were made homeless as their houses were ruined or severely damaged by the falling parts of the bridge. The clear-up operation and demolition of the bridge took many months.

Figure 2-11: Morandi Bridge (Genova) collapse.

No satellite data had been used to observe the bridge, but could it have helped to avoid the disaster? An analysis made in retrospect[22] shows how difficult this would have been. The satellite data would by itself, almost certainly not have been able to predict the failure, but deformations of the structure could have been detected which may have helped to trigger other surveillance measures.

A recent study[22] showed some capability to detect problems but not to the extent of predicting the bridge failure. The study authors record that it:

[22]Pre-Collapse Space Geodetic Observations of Critical Infrastructure: The Morandi Bridge, Genoa, Italy
Pietro Milillo, Giorgia Giardina, Daniele Perissin, Giovanni Milillo, Alessandro Coletta and Carlo Terranova.

"highlights how the availability of new constellations of SAR could be applied to bridge deformation monitoring. While these techniques cannot decisively distinguish between stress accumulation or material degradation processes, they are useful to detect structural distress signs. The map reveals that the bridge was undergoing an increased magnitude of deformations over time prior to its collapse. This technique shows that the deck next to the collapsed pier was characterized since 2015 by increasing relative displacements. The COSMO-SkyMed dataset reveals the increased deformation magnitude over time of several points located near the strands of this deck between 12th March 2017 and August 2018."

Nevertheless, this event is not addressed in our study. Firstly, there is no evidence that there was any ground movement, so this lies outside the core of the case. Secondly, the bridge is not under the responsibility of ANAS and so is not linked to our value chain primary user.

What the collapse does indicate though are the consequences of the road closure. These will feature strongly in our analysis in chapter 5 of the benefits of using Sentinel data. An estimate of the additional costs arising from the Morandi collapse by ISFORT (Istituto Superiore di Formazione e ricerca per Trasporti) gives a figure of €2m per day of which €600k is attributed to additional freight haulage costs[23].

2.6 Data for Informed Decision Making

2.6.1 What decisions?

What types of information will be useful to the road planners and builders to improve the decisions they are making, and how can satellites help? What decisions can be affected and improved? This varies according to the phases of the projects.

Planning phase: Here the decisions being taken are preparing the business case for the proposed road development. A key decision at this time is to select the route and establish legal approvals. Knowing the stability of the proposed route and avoiding parts which have been historically vulnerable can avoid future issues. The use of InSAR provides a unique means to understand the scale and velocity of any movement. It can also identify the degree of risk due to rockslides. The ground motion map will provide easy access to this information which would not be available by any other means.

Design phase: Decisions taken during this phase relate to the type of road construction method to be used. Design decisions can be taken knowing where the ground is moving and most importantly, how fast it is moving in the different parts of the proposed route.

Construction phase: activities during the construction process can themselves trigger ground movement. Decisions taken during this phase relate to detailed engineering and construction tasks.

[23] https://www.themeditelegraph.com/en/transport/2018/09/19/news/bridge-collapse-2-million-per-day-in-extra-costs-1.38081851

These include the safety of the project and the security of the design. Monitoring for unexpected ground movements can indicate unforeseen problems (ie consequences of drilling through impermeable layers) or foreseen ones (settlement of ballast or deposited materials).

Operations phase: concerns the longer-term stability of the road. As in La Spezia, unexpected consequences can be detected, and new conclusions may be drawn. Knowledge of ground motion can help decisions related to timing of maintenance works.

Three types of data can be relevant. Firstly, information on any movement of the ground which may have arisen before any road construction, during the construction or after the works are finished. The spatial resolution of the measurement needs to be consistent with the type of area, i.e. urbanised or countryside. The time separation between measurements needs to be consistent with the type of operation, i.e. close enough in time to detect problems during construction works but may be less frequent as part of the planning phase. The rate of movement is important as an indicator in some situations.

2.6.2 What data?

InSAR ground motion maps are almost unique in what they can offer, and the management of roads can benefit from information related to the movement of the ground in several ways:

- Historical mapping of movement can help planners determine the best routes avoiding unstable areas.
- Mapping of movements taking place at rates of a few mm per day or per week, can identify where construction works are provoking instability. Measured over longer periods of time, these can identify stresses which are building up and which may cause failures of tunnels or bridges.
- Mapping over large areas can show large scale instabilities which are extremely difficult and very expensive to detect using traditional surveying techniques.
- Very precise measurements of movement, possibly using corner reflectors, can be used to improve construction methods for example to determine when ballast or landfill has settled.

As such measurements become available, the security of the road system can be improved as we shall discuss in later chapters.

2.6.3 Limitations of Conventional methods

Several alternative methods exist to measure the movement of the ground surface[24], but these are either less accurate, more expensive or limited in area covered. Only InSAR can offer all three of these attributes:

---

[24] Cost benefit analysis of a proactive geotechnical asset management system using remote sensing. Rudiger Escobar Wolf et al. June 2015.

- Traditional surveys cover a limited area and are labour intensive. They can be made with high precision and close spatial sampling but require a lot of time to be able to measure the movement regularly.
- Overflights using Lidar are expensive to undertake and hence not really suitable for regular measurements even though the accuracy and the spatial resolution are excellent.
- Augmented GPS measurement requires investment in equipment and is limited in accuracy.

In reality, due to the limitations of more conventional methods, ground motion is rarely investigated by road designers. Knowledge of the geology and where problems are likely to occur are mainly used as a guide. InSAR has the potential to be a key tool to be used by road designers and engineers.

3 The Use of Sentinel data

3.1 How can Satellites help with Roads Management?

In this chapter, we look at the use of the satellite data which provides the information services being used to support highways management in Italy. The information which is being used by ANAS comes from a product called “Rheticus” which provides country-wide ground motion maps. The specific product, which is based on the technique called InSAR uses data from radar satellites and in this case, a Synthetic Aperture Radar (SAR) carried on the Sentinel 1 satellite which is part of the European Copernicus programme, so we shall start with a simple overview of the programme to place the services into context.

3.2 Copernicus and the Sentinels

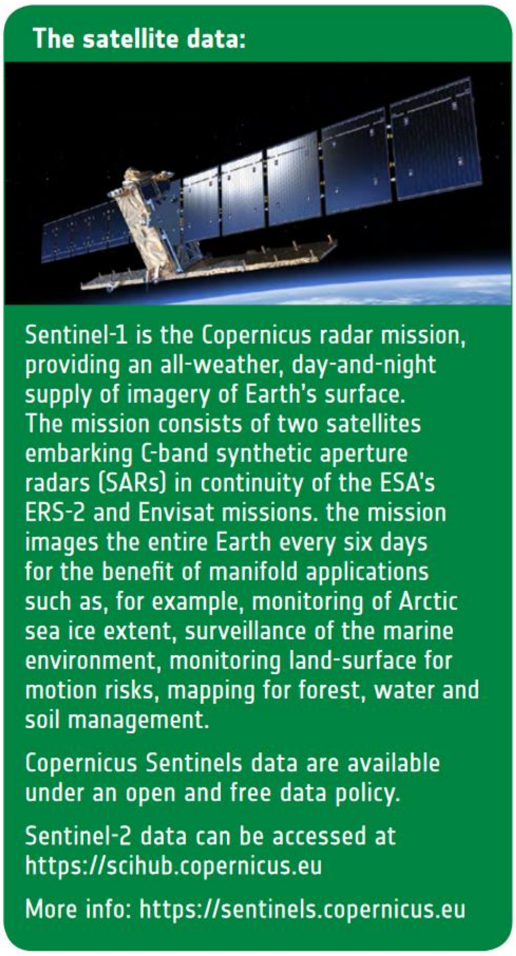


Figure 3-1: Sentinel-1

The case of monitoring road infrastructure is based on data coming from Sentinel-1 (see Figure 3-1) which is used to monitor movements of the ground. The technique, known as InSAR (Interferometric Synthetic Aperture Radar), uses several observations of the ground at intervals of days, weeks and sometimes months, and, using Multi-Temporal Interferometry (MTI) algorithms, is able to detect vertical movements of a few mm which have occurred between the observations. The EU Copernicus programme[25] uses data coming from many satellites to provide global information. At the heart of the programme are the Sentinel satellites which are currently 6 in number (see Figure 3-2).

Our case is defined by Sentinel-1[26] which carries a Synthetic Aperture Radar (SAR) operating in C-band. During the last decades, radar satellite technologies have proven their usefulness to monitor the Earth thanks to the all-weather, day-night capability and the many applications that can exploit their data. More and more application opportunities have emerged, thanks to the improved capabilities of the new space radar sensors in terms of both resolution and revisit time.

[25] https://www.copernicus.eu/en

[26] https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1

Of specific interest for highways management is the SAR Interferometry (InSAR) capabilities which are attractive for different areas of risk management such as monitoring of subsidence, volcanoes, tectonic movements, urban areas and infrastructure and slope instabilities. In particular, the technique allows detecting and monitoring millimetric vertical displacements occurring on selected point targets exhibiting coherent radar backscattering properties, hence the interest for ANAS and for highways management.

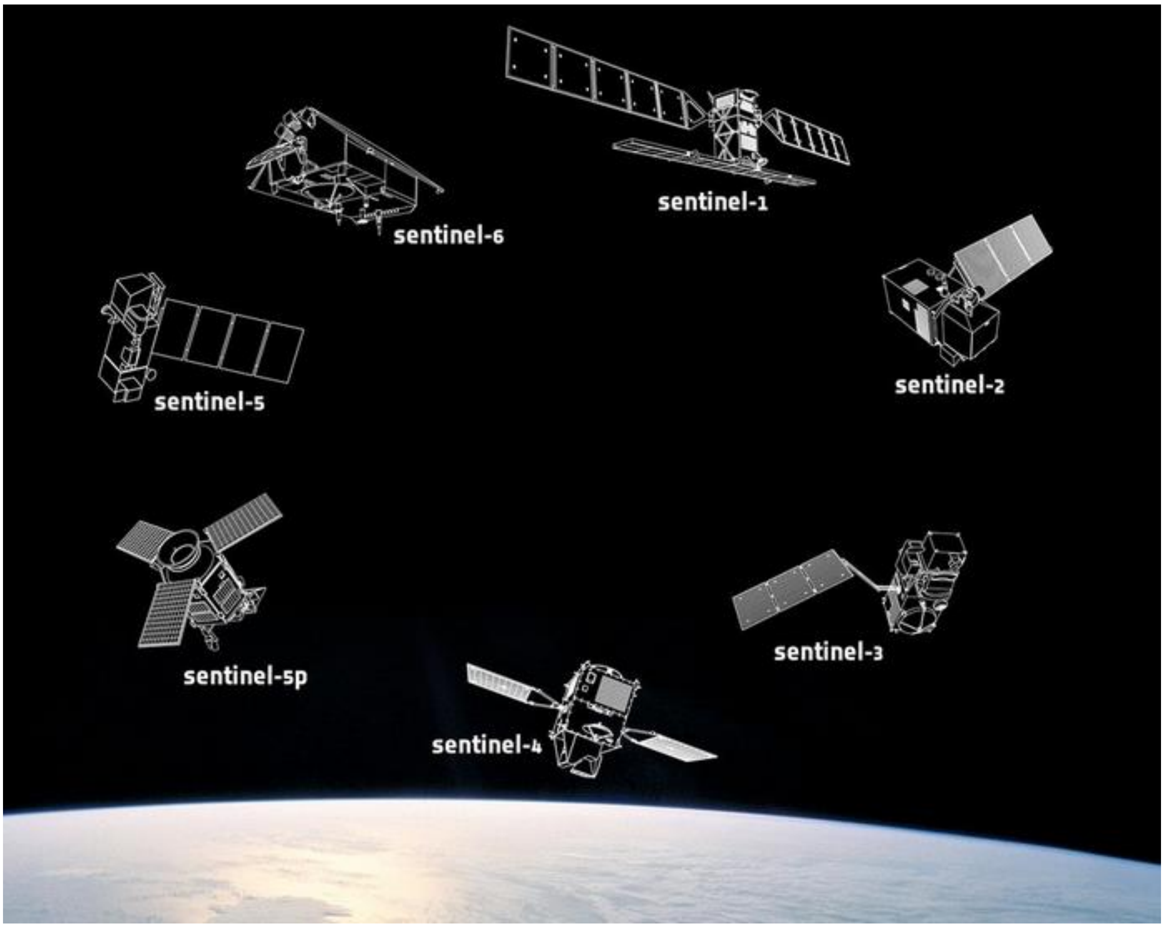


Figure 3-2: Current Sentinel satellites

Sentinel-1 is the latest SAR mission launched by ESA, funded by the EU and ESA Member States with the first - Sentinel 1A - being launched in 2014 followed by S-1B in 2016. The two-satellites Sentinel-1A and 1B provide highly reliable data with a short revisit time, global coverage and rapid data dissemination to support operational applications. Archive data from earlier radar missions: ERS-1/2 and ENVISAT, allows ground instability analysis to be performed back in time almost all over the Earth. It is the only tool able to develop a historical map of ground movement going back to the 1990s when ERS-1 was operational.

The analysis of ground and structure deformations to support the planning, design, construction and operational phases of developing and maintaining highways, can benefit from increased exploitation of affordable remote sensing systems. Synthetic Aperture Radars, such as that on Sentinel-1, are playing a crucial and growing role. Sentinel-1 offers regular, global-scale coverage, free imagery and improved revisit time (less than 6 days) and can now guarantee wider and more efficient application of InSAR for global infrastructure monitoring which is now being applied to the case of highways management in Italy and other countries.

3.3 How can Satellites measure ground movement?

The Principles

A SAR system emits microwave pulses (with a wavelength ranging from few centimetres to few tens of centimetres) and records the echoes from each pulse. The time taken for the echo to arrive provides the distance between the satellite and the measurement point on the ground. The energy that is reflected or scattered back from the ground provides important information on the surface.Since microwave radiation penetrates the atmosphere with negligible absorption, SAR is capable of operating during all weather conditions and at night. These properties for all-weather and night-day acquisitions, make this technology very appealing for Earth surface monitoring purposes.

SAR data are intensively used for the measurement of ground and structure deformations and the key technique used for the data processing is typically mentioned in literature as Multi-Temporal Interferometry (MTI)[27]. MTI has shown, in the last two decades, strengths and capacities in terms of wide area coverage (several tens of thousands of square kilometres) over long periods (several years). With MTI, successive SAR images are compared so that the distance between known points are compared. When these have changed, the radar can detect this.

The basis of MTI-InSAR is that the radar can measure to high precision when a point on the ground has moved closer or further away from the radar. If the radar is carried on-board a satellite, it is hence useful for measuring vertical displacements; but note that it is unable to measure any lateral movements. As the radar signal hits the ground, the intensity of the energy reflected is determined by the nature of the ground surface. If this is strong and stable from one image to another (which may be taken days, months or even years apart, then changes in (the phase of) the signal enable the vertical distance to be measured.

The nature of the ground surface is highly important. If it is covered in vegetation (as in rural areas), then the signal is weak and changes (caused by growth, wind etc) cause the signal to become decorrelated[28] and not useful for measurements of ground movement. This is equally true over large flat surfaces where the reflectance is poor i.e. water bodies.

On the other hand, over man-made surfaces, a strong reflection can come from single points. These are highly effective to measure ground movement. In some cases, a very strong and dominant reflector (known as a corner reflector) may even be placed specifically to help measurements.

[27] J. Wasowski, F. Bovenga, "Chapter 11 - Remote Sensing of Landslide Motion with Emphasis on Satellite Multitemporal Interferometry Applications: An Overview", Science Direct, Landslide Hazards, Risks and Disasters, 2015, Pages 345-403, https://doi.org/10.1016/B978-0-12-396452-6.00011-2

[28] This means that the change is due to the something other than ground movement.

Otherwise, road signs, roadside barriers and other metal objects will provide good measurement conditions – which is often the case along roads.

Frequency of Measurements

The ground resolution and the frequency of observations are both important characteristics in determining where the InSAR ground mapping may be used for effective highways management.

- Ground resolution basically determines how far apart points on the ground may be detected. The nature of the ground is very important so that built-up areas, with many reflectors in close proximity, require much higher resolution in order to identify which point has moved. If too many reflectors are present in the same measurement cell (pixel), then the measurement becomes confused and only an average movement can be measured. Higher resolution images help solve this problem but are generally commercial compared to the Sentinel-1 data which is free.
- The frequency of the observations depends on how often the satellite passes overhead and if images are being collected. High-resolution satellites generally are imaging smaller "swaths" i.e. smaller areas on the ground, and hence will observe the target less frequently. Sentinel-1 has a larger swath width and can provide images every 3 to 6 days over Italy. There is a direct trade-off between the ability to measure single points on the ground compared to taking measurements on a regular basis.

The availability of images from many satellites increases the ability to measure movements either in a closely-space grid (high spatial resolution) or with a shorter delay between each measurement. Note that only images taken with the same satellite may be used in MTI processing to generate ground movement maps.

Measuring Points on the Ground

Some commercial missions also offer high spatial resolution (e.g. 1 m or less with COSMO-SkyMed and TerraSAR-X), but, unlike the free and open Sentinel data, the images must be purchased. Higher spatial resolution allows points on the ground (or on buildings or other infrastructure) which lie close to each other, to be distinguished. Operating restrictions mean that the area of ground covered with 1m resolution will be much less than that covered by Sentinel images of around 10m resolution. Hence the interval between images is likely to be longer.

Even when commercial data is to be used, the lower resolution but free Sentinel data may be used as a trigger beforebuying higher resolution commercial data. But caution, the temporal availability of the higher resolution data may be longer than for Sentinel with a wider swath coverage leading to a trade-off. We have seen this in many other cases.

The use of Sentinel-1 with respect to the other SAR constellations gives the following advantages:

- The wide swath leads to a short revisit period meaning that it is possible to detect signals from targets which are changing more rapidly such as bare ground and crops (which are growing) and detect ground movement adjacent to roads.

- The ground resolution is adequate to allow the detection of ground movement and is sensitive enough to indicate where precise problems may be occurring, thus providing a trigger to look more closely at what is happening. This may be through higher resolution InSAR or other direct measurement, inspection or surveying.
- The free data means that routine processing may be carried out so providing cost-effective SAR images for infrastructure monitoring.

The capability to distinguish points on the ground is also determined by the nature of the point. Objects which reflect a lot of radar energy will dominate the pixel hence, if the point location on the ground is well-known and accurate, movement can be detected and attributed to that point.

The Use of Corner Reflectors

This is the case where corner reflectors are used. These may be deliberately placed in a location where knowing the movement is important and become a part of the measurement system. For example, where construction work is occurring, the use of a corner reflector will enable very precise knowledge of any undesired movement caused by the works. Examples could be for tunnel construction, embankments, ballast used for foundations.

Generally, current capabilities do not allow near-real-time monitoring several times per day. Ground motion can only be detected over periods of days, weeks or months. This is sufficient for many applications associated with highways management, where the rate of motion is generally slow. Hence, as seen in the case of InSAR Norway, there are several ways in which the technique can be used:

- Monitoring of unstable ground leading to remedial measures to prevent or mitigate the impact on road infrastructure
- Monitoring of tunnels and bridges to detect problems before they become widely visible
- In certain conditions, to detect where stresses are occurring in anthropogenic structures (bridges) to identify structural problems.

ANAS has been experimenting with the use

Monitoring Bridges

The use of InSAR to monitor bridges has been the subject of some research projects. In March 2001, a bridge collapsed in Northern Portugal, causing 59 deaths. Analysis of 52 ERS-1 SAR scenes acquired in the years prior to the collapse showed that significant motion of the ground was occurring[29]. The research showed that many measurement points are possible for fixed, man-made structures such as bridges using moderate resolution satellite radar imagery, and that Sentinel-1 will be able to meet many of these needs in the future.

---

[29]Multi-temporal SAR interferometry reveals acceleration of bridge sinking before collapse. J. J.Sousa and L. Bastos. Natural Hazards and Earth Systems Science Journal 2013.

A second study[30] looked at three bridges in Bratislava, Ostrova, and Hong Kong. It concludes that while for new constructions, sensitometers can be built into a monitoring system, effective satellite based InSAR monitoring can take place, on a temporal and spatial basis and that this is most appropriate for existing bridges.

In a third example, a study[31] has examined whether the dramatic and tragic accident due to the collapse of the Morandi bridge in Genoa, Italy could have been avoided. The study led by JPL in the US, concluded that it may have been possible to detect early signs of movement, but that InSAR would not have provided an alert to the collapse.

Technical issues surrounding the detection of motion require man-made reflectors to be visible in the scene being imaged. In most cases, the presence of road signs, panels, and barriers around vulnerable areas will enable the motion to be detected quite accurately.

3.4 The use of the Rheticus® Service

In order to provide satellite monitoring services with a very high level of quality and rapid speed of production, Planetek Italia, an Italian SME specialising in EO value-added services, has developed a cloud-based platform, called Rheticus® named after the unique pupil of Nicolaus Copernicus. The platform provides geospatial application services based on processing satellite images and combining with other geospatial data, environmental data and social (statistical) data. The main services provided by the platform are based on Sentinel-1, Sentinel-2 and Sentinel-3 satellite data. Thanks to these data, Rheticus® is capable of delivering continuous monitoring services of Earth's surface phenomena, such as the urban evolution, transportation infrastructure, landslides, fires or water, gas and sewer pipelines networks monitoring.

To address these needs of the infrastructures operators like ANAS, Rheticus is a service dedicated to supporting the operators of the transport sector; the service continuously monitors the area of interest of the operator, highlighting potential criticalities that may cause the worsening of the infrastructure up to the service disruption. The user-interface with an example of monitoring roadways with summary report, trend of instabilities, and filtering tools, is shown in Figure 3-3.

[30] Potential of satellite InSAR techniques for monitoring of bridge deformations. Milan Lazecky, Danielle Perissin, J. Sousa, Nuno Real. Conf Proc. Joint Urban Remote Sensing Event 2015.

[31] Pre-Collapse Space Geodetic Observations of Critical Infrastructure: The Morandi Bridge, Genoa, Italy Pietro Milillo, Giorgia Giardina, Daniele Perissin, Giovanni Milillo, Alessandro Coletta and Carlo Terranova.

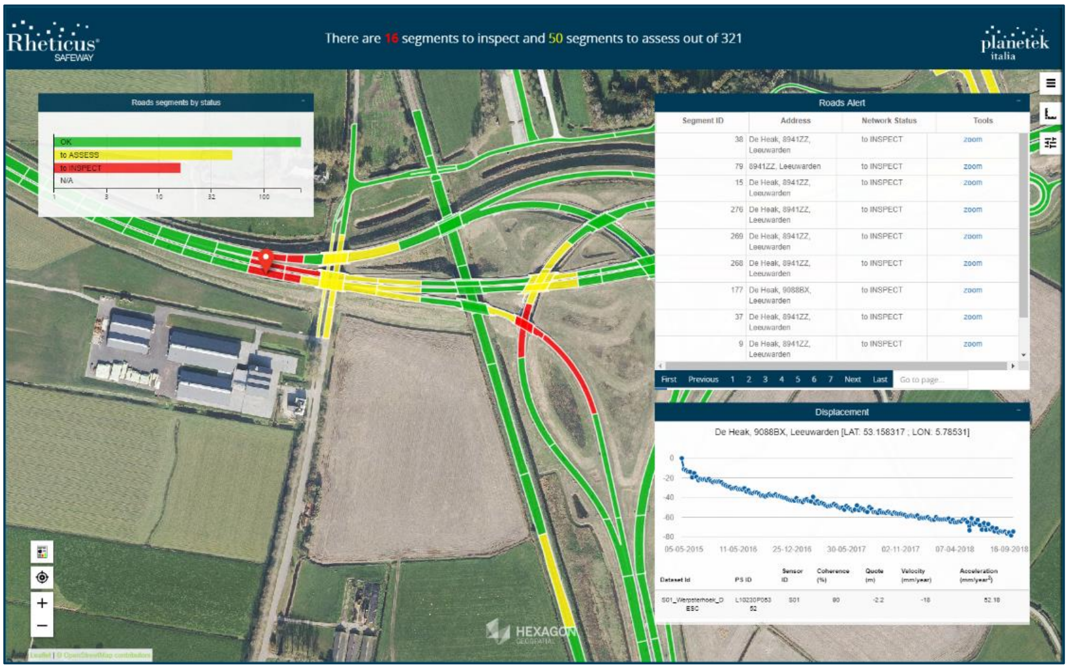


Figure 3-3: Rheticus® Safeway User Interface

Rheticus® Safeway uses Sentinel-1 and Sentinel-2 data defining the locations of concern, so alerting operators to act upon the information. The service is useful to different stages of the life cycle of transport infrastructures:

- Engineering offices in charge of transportation infrastructure planning and design: the service helps to identify the best locations for new roadways and railways by avoiding unstable areas affected by landslides or subsidence phenomena, or it helps to project necessary precautions such as slope-stability intervention predicting and minimising production costs.
- Engineering companies in charge of transportation infrastructure building: the service highlights the effects that construction activities might have on surrounding land, inducing landslides.
- Companies in charge of the management and/or maintenance of transportation networks: the service helps keeping up with road infrastructure management, maintenance, and rehabilitation needs over time with regularly updated data and powered by BI analytics capabilities.

The Rheticus® Safeway service outcome can be also integrated directly within the existing Decision-Support-System (DSS) of the infrastructures operators through dedicated Application Programming Interfaces (API).

3.5 Potential Evolution of the Service

Today, the MTI InSAR has been demonstrated to provide reliable and useful information for the planning and design phases of major infrastructure projects, highlighting the areas that are subject to risks related to the ground deformation phenomena like landslides and subsidence and for operational maintenance support highlighting the infrastructures affected by on-going deformation/ground motion. The use of InSAR is starting to be appreciated inside ANAS and has been used for some specific projects. The main evolution will lie in the uptake of the service and its application to more projects and more complex situations.

A first step will be the building up of larger archives of data which can be used to analyse sites retrospectively. Only InSAR can provide this service and over time, pictures of which parts of the land are moving will be highly valuable to planners and developers. This is the basis behind the separate initiative to establish a European-wide ground movement mapping service[32].

The map will be generated under the Copernicus land service and will have limited updates; the frequency of updates is still under examination. Other services, such as in Norway, are planning an annual cycle which will allow ground movements to be detected prior to further investigations. However, the regularity and rapidity of the updates depend on the underlying conditions which differ between countries and regions and their geography. For example, in Norway, the extended presence of snow over a long period in winter restricts the utility of the imagery for InSAR purposes.

The launch of other SAR satellites will allow a faster reaction time and less latency for the monitoring of construction works or other sensitive sites. Whilst separate maps will need to be produced from each SAR, these can be combined at the map level to improve monitoring capability.

In the future, the integration of existing SAR constellations like Sentinel-1 with the new planned commercial constellations will increase both the resolution and the revisit times. Many acquisitions every day would open the possibility to providing semi real-time monitoring that could be very useful during extreme-meteorological events, for faster response and for semi-real-time failure-prediction purposes.

[32] Copernicus European Ground Motion Service

4 Understanding the Value-chain.

In this chapter, we identify the core value-chain leading from the supplier of EO services to the primary user (ANAS), through engineering and others engaged in road construction or operation to the general citizens and industry which benefit from the improved management of roads and road works.

4.1 Description of the Value-chain linked to Highway Management

As in all the cases which we analyse, the methodology starts by defining a value-chain starting with the provider of satellite-derived information. In this case, Planetek Italia is the service provider. Their customer is the primary user, the Italian roads agency, ANAS, which is now using the ground movement service for major road projects. The 3rd tier of the value-chain comprises those companies providing construction services as well as private road operators. Finally, the beneficiaries of smooth and effective road infrastructure are the haulage companies transporting goods and the general public. These make up the 4th tier of this value-chain. Additionally, some public agencies (beyond ANAS) such as the Italian Ministry of Transport and the Environmental may also benefit.

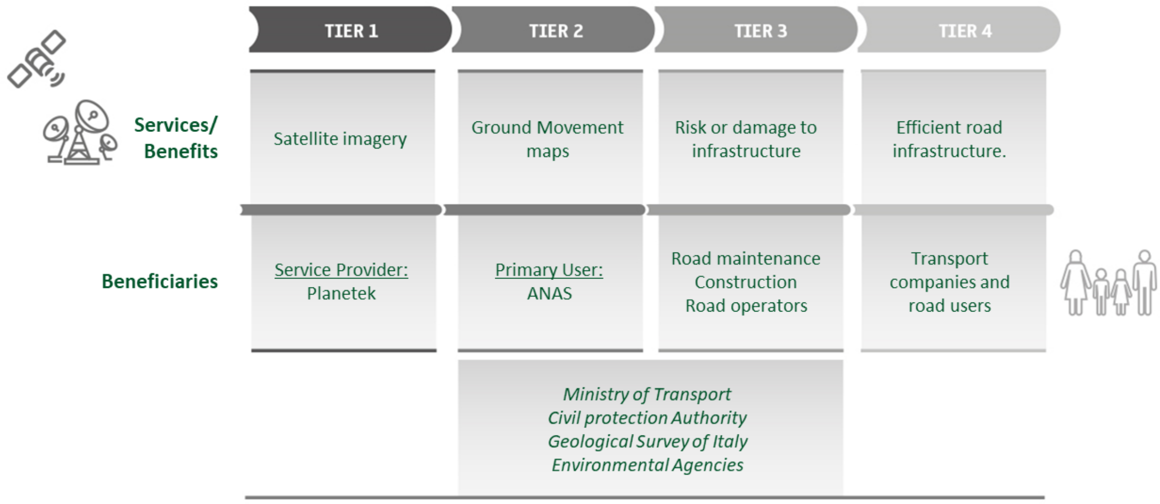


Figure 4-1: Value-chain for Highway Infrastructure Management in Italy.

4.2 The Actors

4.2.1 Service Provider (Tier 1) - Planetek

Planetek Italia is an SME based in Bari in southern Italy with just over 50 employees working on the processing and interpretation of satellite data and providing geospatial products. One of their key services is Rheticus which was used to generate the products used by ANAS in this case.

Planetek was formed in 1994 and has grown with 2 subsidiaries in Italy (Rome and Bari) and one in Greece. Planetek was the winner of the EARSC company of the year in 2017 largely as a result of the Rheticus[33]service and has since won other awards for this innovative product

Their main areas of activity are:

- Satellite, aerial and drone data processing for cartography and geo-information production;
- Continuous monitoring with satellite data of Earth's surface, infrastructures, work sites, urban dynamics or marine coastal areas in support of decision-making and operational activities
- Design and development of Spatial Data Infrastructures (SDI) for geospatial data archive, management and sharing;
- Design and development of real-time, geo-location-based solutions, through positioning systems such as GPS/Galileo/GNSS and indoor location systems;
- Development of software for the satellite on-board data and image processing and for ground segment infrastructures.

Planetek Italia is also a dealer of Hexagon Geospatial / Intergraph software and a data provider of satellite images.

4.2.2 Primary User (Tier 2)– ANAS (Highway Management)

ANAS – *Azienda Nazionale Autonoma delle Strade* orNational Autonomous Roads Corporation- is an Italian, joint stock company wholly owned since 2018 by Ferrovie del Stato Group (the Italian railways company). ANAS is a recognized global leader in the design and management of road networks. For 90 years ANAS has been managing and improving the road network in Italy; longer than any other highways agency in the world! ANAS employees over 6000 people many of which are planners, engineers and architects running projects aiming to expand and continuously develop and improve the road network. Investments have been running at a level of approximately €3 billion per year which has recently been increased.

ANAS was founded in 1928 and became a state-owned company in 1946 to make good the damage sustained by the roads and highways as a result of the war. Since then, it has expanded its range of services, providing support to public entities and spurring roadway design, construction and maintenance — in Italy and abroad. Today, ANAS is responsible for 32,000km of roads throughout Italy (Table 4-1).

The network includes over 2,100 tunnels and 15,800 bridges all of which are vulnerable to movement of the ground.

[33]https://www.planetek.it/eng/news_events/news_archive/2019/11/smart_city_awards_2019_barcelona_rheticus_awarded_with_hera_group_use_case

Motorways / Autostrade	939km
Link roads	355km
State highways	25,002km
Roads currently changing category	713km
Interchange and junctions	4,936km
TOTAL	31,945km

Table 4-1: Length of the roads under the direct management of ANAS.

The primary mission is to ensure the territorial continuity of the Italian road network and an ever safer and more efficient infrastructure; a significant challenge given the complexity of Italy's geology, which relates directly to our case. A good example is that the 1,900 tunnels managed by the company represent half of those that exist in Europe! The Italian road network should also link internationally with neighbouring countries respecting all border requirements and conforming with European standards.

ANAS is not just managing the construction and improvement of the road network. The company is directly responsible for operating a large part of the network which means dealing with daily problems as they arise.

- Motorways and motorway junctions: with over 1294 km of highways and **toll roads**, means that ANAS are the second largest, national operator.
- State roads: 90% of Italian state roads are managed by ANAS; the road network is widespread over the national territory with a strong concentration in the South.

With a value statement saying it"*builds growth, development, progress and the future of the country. Since 1928, our road network and infrastructure has made possible meetings, exchanges, relationships, sharing, knowledge and common culture",*the impact of ANAS' work is felt by every citizen in Italy.ANAS is responsible for overseeing the whole network and for operating directly 29,214km of highway as shown in Table 4-1. The ANAS network of roads for which it is directly responsible is shown in Figure **4**-**2**.

Figure 4-2: Map of the roads under direct Operational Management by ANAS.

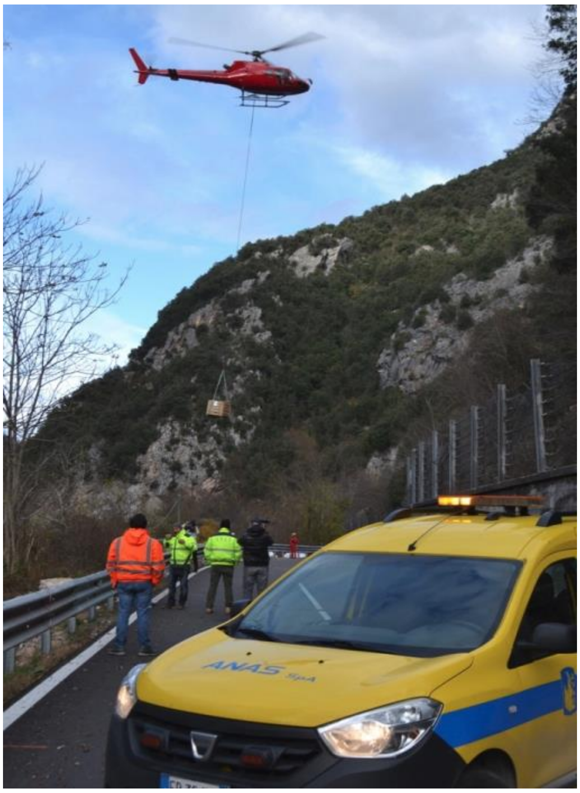


Figure 4-3: Umbria - Central Italy earthquake, installation of rockfall barriers on the SS685, transport by helicopter. Courtesy ANAS.

The map shows the density of the ANAS road network is greater in the South of Italy than it is in the North. Just over 20 years ago, when ANAS was re-organised, many regions in the country took direct responsibility for their minor state highways. This was the case in the north and west of the country (but not Sardinia) leading to the network managed by ANAS as shown in Figure 4-2. This trend has been reversed in recent years such that by 2018, some 7,000km of roads have been returned to ANAS management.

ANAS responsibility is to take care of roads from the design, starting from the feasibility study and the environmental impact assessment, up to the construction and the subsequent maintenance. In 2016, ANAS invested €1.7b in improving the network. 2016 was the first year of a new investment plan which foresees ANAS investment increasing to €3b per annum and a total investment in the road network (by all partners) of €29.9b in the 5 years 2016 to 2020. This budget comes from national attributions through ANAS as well as regional and local funds and from private partners. ANAS oversees the works carried out under these plans.

Figure 4-4: Marche - Central Italy earthquake, technical checks on viaducts.

4.2.3 Road Construction Companies & Operators (Tier 3)

Once the decision to go ahead with a project has been taken – which may take many years, a contractor is sought to undertake the construction project. Most construction projects will involve a consortium of contractors with architects, engineering consultancies, as well as the construction companies themselves. One particular facet of the engineering and construction sector in Italy, which is not necessarily the case in many other countries, is that the infrastructure requires systematic proofing against earthquakes and seismic activity; which links directly with the use of InSAR as a monitoring tool.

The consortium may benefit from the use of InSAR in several ways; some of which are similar to those benefits felt by ANAS:

- Gathering an historical picture of the area under investigation.
- Monitoring the progress of construction and impacts on the ground surface
- Monitoring settlement of the ground in case of in-filling
- Managing disputes in the case of ground settlement

Various specialists are involved in the construction of the roads:

a) Construction Companies:

Those which will most often lead a consortium and execute the actual construction of the road. Some of the leading construction companies in Italy are listed below. Many also operate internationally 4 of these (Saipem (23), Salini Impreglio (62), Astaldi (85) and Danieli (97)) are in the top 100 construction companies world-wide[34].

- Astaldi S.p.A.
- CMC di Ravenna
- Condotte SpA
- Danieli
- ICM
- Impresa Pizzarotti & C. S.p.A.
- Maire Tecnimont
- Saipem
- Salini-Impreglio
- Trevi SpA

b) Specialist engineering companies which perform the overall and detailed design as well as the planning of the project. These are likely to be the more direct users of InSAR technology. Many of the construction companies will have their own in-house engineering services. Specialist engineering companies will be called upon the look at the seismic risk of the project, ie vulnerability to earthquakes, tunnelling works, to tackle more complex projects which may involve other infrastructure such as railways, and/or to consider the environmental impacts. Each of these specialists may be part of a project consortium.

c) Companies specialising in tunnelling; many construction projects involve tunnelling. "Società Italiana Gallerie" (The Italian Tunnelling Society[35]) has been dedicated to divulgating its expertise on tunnelling operations and major underground constructions for over 40 years. SIG is a scientific non-profit association, founded in 1974; it mainly promotes and coordinates studies and research in the field of tunnelling and underground construction works. The association takes actively part in the ITA-AITES Working Group (WGs) in order to share expertise and technical, scientific and business know-how in underground construction. SIG currently counts **more than 650 members**, which represent public bodies and research organizations, general contractors, construction companies and manufactures, as well as engineering firms, consultants and universities.

d) Seismic specialists; the Associazione Geotecnica Italiana is the national association bringing together seismic engineers throughout Italy. The main purpose of the Association has always been to spread the geotechnical culture in the scientific and professional field. The AGI organises many conferences and workshops and is very active on the International stage representing Italian interest in many international bodies. The AGI was formed in 1947 and has grown to around 800 members today.

Once built, the highways enter into operational use. The motorway network is around 6,800km in length with a mix of tollways and toll-free. ANAS owns and operates directly 1,294km of the

[34] https://www.enr.com/toplists/2015_Top_150_Global_Contractors1

[35] http://www.societaitalianagallerie.it/Prj/Hom.asp

motorway network[36] whilst the rest is operated by private companies through concessionary arrangements. The highway operators are responsible for maintaining the highways under concessions and to plan the appropriate investments. This is a rigorous and often complex process balancing the interests of the various stakeholders. The two main operators are Atlantia and SIAS.

a) Atlantia[37].

Atlantia is the largest operator of highways in Italy and one of the largest in the world. Atlantia is a global leader in the motorway and airport infrastructure sector operating in 23 countries. The Group manages 14,000 km of toll motorway, Fiumicino and Ciampino airports in Italy and the three airports of Nice, Cannes-Mandelieu and Saint Tropez in France with over 60 millions of passengers a year[37].

In Italy, Atlantia holds 7 concessions which cover 3255km of highway (see Figure 4-5). Included within the network run by Atlantia is the Morandi bridge in Genoa which collapsed in 2018. Atlantia has come under considerable pressure regarding its security, surveillance and maintenance practices and is threatened with revocation of its franchise to run the highway network.

Figure 4-5: : Highway network managed by Atlantia

b) SIAS

SIAS, a wholly-owned subsidiary of ASTM, is the other leading concessionaire in Italy. ASTM is the second-largest operator in the world with a total of 4,594km of highways under its control in Italy and Brazil as well as the UK. In Italy, ASTM operates 1423km of network, mainly in the north-west of the country (see Figure 4-6).

36 http://www.stradeanas.it/it

37 http://www.atlantia.it/en/

Figure 4-6: Highway network operated by SIAS/ASTM

The highway operators are responsible for maintaining the highways under concessions and to plan the appropriate investments. This is a rigorous and often complex process balancing the interests of the various stakeholders. Atlantia (or rather their subsidiary, Autostrade per L'Italia) provides a useful overview of this process on their website[38].

4.2.4 Citizens and Society (tier 4)

Road transport has come to play a fundamental role in modern life. Both for the movement of people and for goods, road transport is the most important means of transport in terms of numbers of passengers and of goods moved. According to Eurostat[40]:

- For passengers, some 94% to 95% of passenger-km are made on the roads ie. Around 5-6% of trips are made by rail.
- For goods, around 80% of the total freight is transported by road although this has been falling slightly over the last few years (see Figure 4-7)

This is further illustrated by the importance placed by Italians on car ownership. Alongside Luxemburg and Spain, Italy has one of the highest ownership rates of motor vehicles in the EU and the world. According to the World Bank[39], Italian citizens own 692 cars per 1000 citizens and 80 cars per km of road. For a large country, it is one of the highest global ownership rates.

[38]http://www.autostrade.it/en/la-nostra-rete/iter-approvativo-di-un-opera
[39]https://web.archive.org/web/20140408034906/http://wdi.worldbank.org/table/3.13

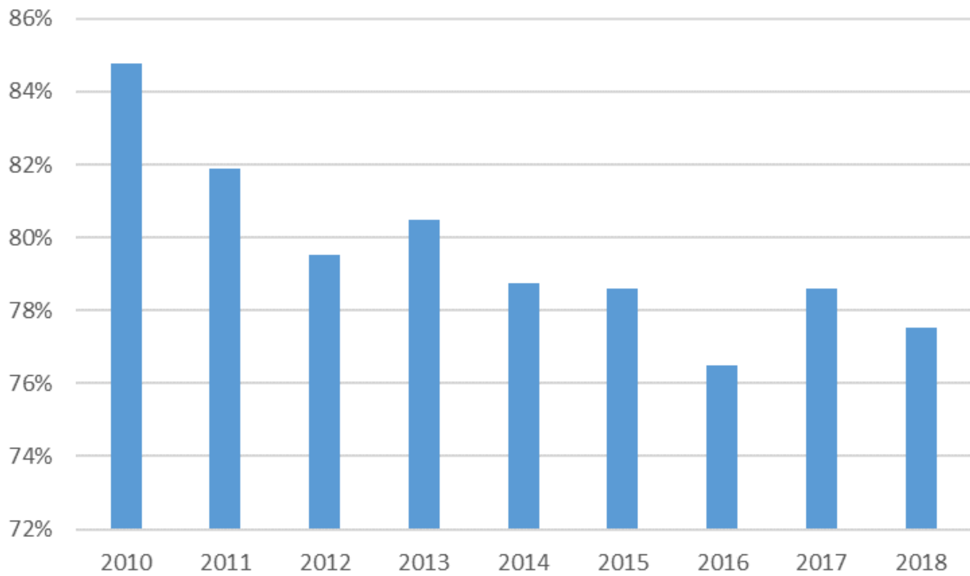


Figure 4-7: Percentage of goods carried by road in Italy[40]

Accidents, as reported above, where bridges collapse leading to motorway closure are happily rare. Nevertheless, for any closure to a major road or highway, the disruption caused is very high. In the case of the Morandi bridge, the consequences were severe as traffic was diverted around Genoa. For the A6 motorway, the consequences were less but local travellers still faced delays and additional journey times for more than 3 weeks.

Hence, the avoidance of situations where roads need to be closed is of great benefit to the local citizens with sometimes wider implications in the case of heavily used highways. We cannot distinguish these with a much more detailed analysis but do include the impact in our evaluation.

4.2.5 Other Stakeholders

The Geological Survey of Italy

The Geological Survey[41], which has been producing maps of Italy for over 130 years following the unification of the Kingdom of Italy in 1861, is now part of the Environmental Protection Institute (Istituto Superiore per la Protezione e la Ricerca Ambientale) or ISPRA. The survey produces geological and thematic maps of Italy which are used extensively in the planning of infrastructure. The geological survey is explicitly consulted by ANAS concerning the geology of proposed routes. This will include any information existing on sites of ground movement noting that this is limited before InSAR has become available.

Civil Protection Authorities

[40] Source: Eurostat - https://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do
[41]http://www.isprambiente.gov.it/en/environmental-services/the-geological-survey-of-italy

The Protezione Civile (CPA) in Italy is responsible for preparedness and response to natural disasters: earthquakes, floods, landslides, volcanic eruptions, fires. Italy has a high exposure to these natural risks. EO-based products and services empower the operational capacity of the CPA to manage the disaster cycle associated with these risks, in particular for preparedness/mitigation & recovery/reconstruction phases.

Ministry of Sustainable Infrastructure and Mobility (MIMS)

MMIS has overall responsibility for the transport system in Italy and the links to the rest of Europe and especially the transport corridors identified under the EU TREN (Trans-European Networks). In April 2017, MMIS approved a new infrastructure plan for Italy called "Connecting Italy". The plan outlines its vision for the transportation and infrastructure system up to 2030. The scope of work includes the renewal of the public transport fleet, the upgrade of existing, and the development of new, metro and tram lines, and extension of the mass transportation network. With the launch of this plan, MIMS aims to meet the mobility demand of passengers and freight as well as connect the various areas of the country (in particular, cities, industrial centres and tourist places).

To meet environmental goals, the plan focuses on developing road alternative infrastructures; rail, sea and urban metro and tramways. However, it includes measures to improve traffic flows in key corridors as well as traffic management systems.

National Institute for Geophysics and Volcanology (INGV)

The INGV houses the National Earthquake Centre for Italy as well as 2 other departments for volcanology and for the environment. The centre is the largest in Europe and the 2nd largest in the world after the USGS. INGV works very closely with ENEA, the national agency for new technology, energy and sustainable economic development.

INGV is working with the "Strada dei Parchi" company which manages the highway connecting Rome with the Adriatic coast for the planning of a monitoring system using in part, satellite data for ground motion measurements. The project is still awaiting approval.

INGV and ENEA made an agreement in 2018 to work together on the Italian node of the European Infrastructure Simulation and Analysis Centre (EISAC). The EISAC is a collaborative platform at the European level in the domain of critical infrastructure protection for supporting operators and public authorities in better protecting assets and in enhancing their resilience with respect to natural and man-made hazards.

5 Assessing the Benefits

In this chapter, we look at the benefits which are obtained by using the Sentinel-1 derived ground movement maps. Each tier in the value chain is evaluated given the different nature of decision-making stemming from the use in different phases of road construction and operational management.

5.1 The Service Provider (Tier 1) - Planetek

Planetek introduced the Rheticus service in 2016. Since then, it has become highly successful and has led to several awards to Planetek. As a result of introducing Rheticus, Planetek has grown with 5 persons now working directly on the Rheticus service. ANAS has been one of the early customers for the service and has recognized its value. As a result, the use of InSAR technology to measure ground movements and has started to be included in contracts for surveying and monitoring of sites and infrastructure covering all phases of projects. This provides new opportunities for Planetek and other EO service providers to bid for and win project work and services.

Innovation has been at the heart of Rheticus both in technical terms and from a marketing perspective. The approach to offer services using EO is relatively new but is growing rapidly[42]. Traditionally, EO products have been bespoke with one product for a dedicated customer ie a consultancy-based approach. Planetek has been an early mover to offer a service which can be used by a customer for a service fee. This is the case for Rheticus where Planetek offer access to a portal where ground movements are mapped across Italy.

Further innovation has been in the technology used. Whilst InSAR is a technique known since the 1990's after the launch of ERS-1, the processing of such large volumes of data and the algorithms to get accurate results have evolved. Skilled data engineers have improved the service which is now appreciated by ANAS.

We shall not discuss the cost of providing a full service to ANAS since this cost will come out of the equation as it appears on both sides. But, with ANAS as an anchor customer, Planetek has been successful in other tenders and there is a clear leverage in terms of additional jobs and to the business.

Indeed, Planetek has won further tenders with ANAS since the use of InSAR technology has been recognized as a useful tool for monitoring sites during construction work.

[42] EARSC Industry Survey 2019 & 2020.

5.2 The Primary User (Tier2) - ANAS

5.2.1 How we approach the problem

To understand the benefits, real or potential, to the road management agency, we shall take a number of instances of the use of the ground movement maps for projects and look at each one separately. Since every situation is different, we need to understand the processes followed and the decisions which are being taken. We shall firstly identify a list of indicators and then the proxies and assumptions which will allow us to analyse the benefits.

In the case of ANAS, we take the single service which can be applied to different decision-making processes within ANAS. Since the organisation is project-based, we need to examine these projects as a primary approach before extending each one based on assumptions around the nature of the projects and the decisions being made in each one. Note the decisions are similar according to the phase of the project which then become our focus for analyzing the benefits to ANAS and along the subsequent value-chain.

In each phase of the road management task, the same basic product is used to support different activities and hence leads to different types of decision. Furthermore, the scale of each activity and decision is linked to the scale of the project but also to the nature of the project; some carry more risk than others. Hence it will be difficult to establish generic metrics with which to estimate the benefits.

The very limited number of projects where the ground movement maps have been used compromises the accuracy of the analysis. Nevertheless, the instances are real and can serve as examples and a reference against which further analysis can be judged. This should lead us to a realistic appraisal of the potential benefits when considered for all the ANAS projects for which it is relevant.

5.2.2 Reduced survey costs

The first indicator is that linked to the possibility to reduce survey costs. For most projects, a survey of ground movement is not included in the traditional surveys of the routes largely due to the high cost. The introduction of InSAR and the free and open data policy for Sentinels changes this. In what ways can this benefit ANAS?

In the planning phase, the ground movement maps are used to help in the selection of the best route to take and as a result, provide a good first estimate of the cost to implement the project – which will set the overall budget. A more informed decision for the route, as a result of using InSAR, can reduce the risk of encountering problems later and especially during the construction phase.

This applies also during the design phase when knowing that a section of the route is vulnerable to movement can influence the design to reduce the risk of technical or geological problems showing up later. Most of the problems will show up later in the project during construction or even in the following operations phase. Adapting the design to the geological conditions is fundamental and hence, knowing that a part of the route is vulnerable is a key piece of information.

When a route is being planned or a design made, the geological experts in ANAS will assess the proposed options and identify those areas which are considered to be a risk. Inherent in their evaluation is a mandatory consideration of seismic risk. Currently, they are supported by information coming from the Geological Survey Institute; now part of the Environmental Institute (ISPRA). This may include the use of ground sensors deployed as part of a geological survey which may include GPS positioning sensors. However, whilst GPS can provide good lateral accuracy and detection of movement, it is less capable to detect vertical change.

InSAR offers big advantages in terms of cost and accuracy as a means to detect ground movement. An assessment of different techniques for measuring vertical displacement has been carried out by the Michigan Technical University[43]. This compares three methods (InSAR, LIDAR and in-situ measurements ie augmented GPS) and comes to the conclusion that InSAR is by the far the cheapest even when commercial data must be purchased, and further that it outperforms the alternative techniques using in-situ sensors, drones and/or GPS.

We can confirm this having looked at a similar use in Norway. Here it was very clear that only InSAR can offer country-wide coverage, at a useful spatial resolution (of the order of 10m), and an impressive accuracy (millimetres of movement). But InSAR also offers another big benefit in that historic data can be obtained using radar data from earlier satellites (ERS, Envisat, Radarsat, Cosmo-Skymed) allowing us to “look back in time”. This is not possible using conventional approaches since the data has simply never been gathered.

The Quadri project.

Ground movement maps were used by ANAS in support of the planning of the Quadri project. Here, satellite data was used to confirm ongoing geological movement that were measured in that area in a previous, preliminary evaluation phase. The ground instruments used earlier were no longer available, and the satellite-based approach was used instead.

In this specific case, due to spatial resolution and vegetation, the number of measured points has not been as high as desired. Since historical data is being used, experts must rely on existing measurement points showing up in the images (see discussion of InSAR in chapter 3.1). Nevertheless, the analysis has been able to show, at many points the absence of slow ground movement, and in this case the high temporal frequency (revisit) of Sentinel has been really useful.

Qualitatively, ANAS say that:

The information derived from SAR data are useful, and the benefit of their usage is very high, with respect to the possible costs. In this specific case the data have shown the absence of critical phenomena.

Up until the launch of Sentinel-1A in 2014, limited imagery is available and hence an InSAR map can only be made in a few places where good data exists. Since the launch of S-1, regular images have

43 Cost benefit analysis of a proactive geotechnical asset management system using remote sensing. Rudiger Escobar Wolf et al. June 2015.

been gathered, with much wider coverage over the whole of Italy. This allows country-wide maps showing ground movement to be generated using Rheticus or other services. With time, the history of ground movement for all sites in Italy will become routinely available; making this service even easier for ANAS and others to use.

The Quadri project (see text box) and a second project in Lazio (see chapter 2.4) illustrate the benefits in a qualitative fashion. The decision has now been taken within ANAS that InSAR ground movement surveys should be more widely across all the projects. Several tenders have now been released which include a specific request to use InSAR to monitor the project execution. On this basis, we shall make a quantitative assessment comparing the costs that would need to be spent on a survey using traditional methods and the ones accrued using InSAR.

For our assessment, we make the basic assumption that one survey is made for each project; which is a conservative assumption given that some projects may require more than one survey. With this assumption, the total number of projects we are using in the calculation below equates to the total number of surveys each year irrespective of whether they are conducted in the planning phase, the design phase or even during construction.

The assumptions we have made to calculate the potential savings in survey costs are:

1. How many works are carried out each year? ANAS is investing around €3b per annum in the road network. If the average cost of a project is taken as €50m then this represents 60 projects are started each year throughout Italy (note that this does not mean they take 1 year to complete!).
2. Not all of these will cross land which is vulnerable to movement. How many of the 60 projects can benefit from a survey of ground stability? We have assumed a minimum of 20% (15 surveys) and a maximum of 50% (30 surveys) with a nominal case of 20 surveys.
3. The cost of a “traditional” survey to assess the ground stability ie several, repeated surveys plus the use of deployed movement sensors can be in the range €50k to €500k with an average of €100k per project.
4. The cost of the InSAR survey is estimated to be in the range €25k to €250k with an average cost of €50k. This is half the cost of that assumed for a traditional survey.
5. Not all projects will require the same degree of surveying. Our assumption is that 40% of those projects requiring a survey will need only a minimum survey, whilst 50% will require an average one and 10% will need an extensive survey. These numbers are applied to the range of projects estimated to be vulnerable to ground movement and hence benefiting from a survey.

Performing more detailed surveys during the planning and design phase will have consequent impacts for later stages by providing improved references (ie ground stability maps) to be used by the contractors as well as potential savings as identified during the construction phase. For the sake of a conservative analysis, these savings are not included in the analysis.

Benefits in the Planning & Design Phase	Minimum	Nominal	Maximum
Number of construction projects started each year		60	
Number of projects each year for which a ground movement survey is relevant	15	20	30
Cost of a traditional survey monitoring ground stability (simple to complex case)	€50k	€100k	€500k
Cost of an equivalent satellite-based survey monitoring ground stability	€25k	€50k	€250k
Percentage of relevant projects needing :-			
Minimal survey		40%	
Nominal survey		50%	
Extensive (maximum) survey		10%	

Table 5-1: Assumptions leading to the Benefits in reduced survey costs

	Minimum	Maximum
Minimal survey (40%)	150k	300k
Nominal survey (50%)	375k	750k
Extensive survey (10%)	375k	750k
Total potential savings	€0.9m	€1.8m

Table 5-2: Calculation of the benefits of reduced survey costs

Table 5-2 shows the calculated benefits arising from having the InSAR service available compared to estimated costs for a traditional survey.

The lower cost of a satellite-derived survey also opens the possibility to use it more often. This will translate into a lower risk for ANAS of spending on redesign or remedial works either during the construction phase or after the works are completed.

5.2.3 Reduction of risk (and cost) of remedial works

The second indicator is linked to the reduction of risk of needing and hence spending on subsequent (re)works. During the design phase, the more precise planning of the project takes place. This will include the design approach to be adopted for the road. In Italy, due to the very high seismic risk, all structures are required to be designed to resist an earthquake. However, some ground geological conditions are more vulnerable than others and hence, knowing that a particular area of ground has moved in the past, or is moving in the present can influence the design which should be adopted.

The tunnelling at La Spezia (see text box) is an example where using InSAR early in a project could lead to better identification of risk and savings on the cost of remedial works. Note that InSAR has only been used in the latter stages of the project once the problem had been uncovered through other means.

La Spezia:

The tunnel being constructed at La Spezia just outside Genoa to connect the port, the state road and the motorway, has suffered significant engineering difficulties. Construction was well advanced before it became apparent that there were some problems with ground movement which were causing houses on the ground above the tunnel to move leading to cracks and instability. It is believed that this movement is not entirely caused by the tunnel but is inherent in the geology but has been significantly aggravated by the tunnelling works.

The consequences are twofold. Firstly, there is the question of liability payments to the house owners. Secondly, and more significantly, the tunnel needs to be moved. The road construction leading to the tunnel was well advanced, with bridges and pylons lifting the road between the valley floor and the mouth of the tunnel which will need to be moved as well if the mouth of the tunnel is moved.

Once the problem was identified, InSAR was used to understand it better by mapping the precise location and the speed of movement.

Currently, the project is being completed using the original route with slope stabilization through complex geotechnical engineering works. ANAS have been studying the rework options including to reinforce the roof of the tunnel and stabilising the ground above it or to move the mouth of the tunnel and the consequent rework of the road. The budget for the project is €51m of which around 32% will be for water drainage and other interventions. These additional costs may have been avoided or at least mitigated by the use of InSAR monitoring which could have been able to detect the problem earlier.

The additional costs incurred for the La Spezia project amount to around €17m. In addition, in a separate incident, a landslide was triggered in the same area which led to the construction of a protective tunnel, costing €15.2m. It is possible to argue that all this additional cost could have been avoided had the problem been identified during the design phase. However, to be on the conservative side, we shall make the assumption that 20% of this cost could have been avoided.

Not all rework will be as expensive so, to get a handle on the benefits we are going to assume that each year there may be 1 or 2 projects with additional costs around €15m and 2 or 4 projects with a much lower cost impact of €1m. The 20% attribution to the use of InSAR will be applied to these figures. Furthermore, systematic use of InSAR to monitor the ground movement will itself have a cost which we shall assume as €1m per year which will be deducted from the benefit. The calculations for the minimum and maximum cases are shown in Table 5-3.

Palizzi

The construction of the Palizzi "S.S. 106 "JONICA", in the very south of mainland Italy has been subject to landslides during tunnelling works. After experiencing similar problems elsewhere (including La Spezia), ANAS decided to use the InSAR monitoring technique through the Rheticus service during the design phase. This has led to the decision to deploy 18 corner reflectors which will be used to monitor the site during and immediately after the construction works.

Monitoring will continue with the ongoing phase of the work (thirty-six months) and for a period of twelve months following their completion. The type of corner reflector being installed for the construction of the southern carriageway, is shown in Figure 2-9.

	Minimum		Maximum
Additional cost for each project affected by ground instability	€1m		€15m
Percentage of the added cost which can be saved by early detection	20%		20%
Benefit of the early detection	€0.2m		€3m

Benefits resulting from reduced design risk	Minimum		Maximum
High Cost projects implicated each year	1		1
Value benefit for minimum scenario	€3m		€6m
Low cost projects implicated each year	2		4
Value benefit for maximum scenario	€0.4m		€0.8m
Benefits coming from the use of ground movement maps	€3.4m		€6.8m
Annual cost for satellite-based surveys	€1.0m		€1.0m
Net Benefit	€2.4m		€5.8m

Table 5-3: Savings on remedial costs through reduced design risk

We noted earlier that ANAS is spending around €3b p.a. on works and so these figures represent about 0.1% savings on the overall budget as a result of using InSAR.

5.2.4 Reduced project delays

Throughout the project, becoming aware of problems earlier can help save time and cost. Whilst in early phases identifying ground movement will impact the nature of the project more than the time it takes, problems identified earlier during the construction phase can have a big impact.

Once construction has started, engineering works can themselves trigger movements (see text box – Basilicata). These may be due to slipping inclines or changing underground water flows amongst possible causes. The movement is difficult to detect and costly using traditional methods as we have already discussed. In consequence, rarely are any measurements made until the consequences become noticeable and can lead to costly disputes and project delays whilst causes and responsibilities are identified. The use of InSAR can help overcome these issues and savings would be made due to a faster resolution of the problem.

In terms of savings for ANAS, these are assumed to be relatively small. We shall make the broad assumption that up to 50 project weeks of delay could be saved each year by using InSAR mapping to detect problems, ie 50 projects each avoiding the loss of 1 week or 1 project saving 50 weeks with a minimum of 25 project weeks. Recall that the La Spezia tunnelling has delayed this project by 2 years at least which, whilst an extreme example does support the assumption. We make the conservative assumption that the cost to ANAS of a project delay is 20k per week lost. Hence, we consider that ANAS could save €1m each year through the use of site monitoring during the construction period.

5.2.5 Reduced risk (and impact) of disputes

The third benefit arises due to a reduced litigation/dispute risk between ANAS and the contractor or other interested parties. In the project discussed earlier for the construction of a viaduct in Basilicata, ANAS and the contractor disputed whether subsidence was arising due to the construction works. No satellite data was used. Ultimately, movement was detected using in-ground sensors. The presence of many construction materials gave rise to many detection points so restricting the degree of movement InSAR could detect. Nevertheless, it is possible that Sentinel

Basilicata

The construction of the viaduct Santo Stefano on the SS655 connecting Matera with the city of Foggia has led to some movement of the ground around pylons anchoring the bridge. The construction company first reported the issue which was disputed by ANAS. As a result, ANAS placed inclinometers to a depth of 70m which revealed movement some 20m below the surface.

InSAR would detect movements which are visible at the surface. In this case, the infrastructure – the pylons – were moving and could have been detected due to a large signal coming off man-made structures. However, other man-made structures in the immediate neighbourhood of the pylons, which were not moving, hid the actual signal from the pylons.

The story shows the potential for InSAR to detect movements triggered by the construction works but the conditions need to be clearly understood. By detecting such issues early, valuable project time can be saved, and evidence is available to identify liabilities.

In the future, ANAS would consider using InSAR based terrain movement maps in cases like this, to save time debating the subject and to avoid the strong risk and legal issues with the construction company with potentially expensive consequences.

1 data would have been adequate to detect the movement without necessarily being able to pinpoint the cause.

Whilst real and tangible, we do not feel able to place a value on this due to its infrequent nature and hence lack of any references, plus the scale of the dispute. We recognise that there is a benefit to ANAS but cannot quantify it.

5.2.6 Overall Benefits to ANAS in Tier 2

To summarise, the overall benefits to ANAS (except in operations which are considered part of tier 4) are shown in Table 5-4.

	Minimum	Maximum
Reduced Survey costs	€0.9m	€1.8m
Savings on Remedial works	€2.4m	€5.8m
Savings on avoiding project delays	€0.5m	€1.0m
Total Economic Benefits	€3.8m	€8.6m

Table 5-4: Summary of ANAS economic benefits

5.3 Road Construction & Operation (tier 3)

Tier 3 is covering those concerned with the construction phase of the road and the operations of highways. Construction and engineering companies are contracted to develop or repair the infrastructure whilst service companies such as Atlantia contract to operate the highways. There are several ways in which they can benefit; indirectly as a result of decisions taken by ANAS or directly through using InSAR mapping themselves (possibly mandated by ANAS as a contractual requirement).

The benefits arise in several ways:

- Time saved on projects through reduced delays
- Avoiding the cost of remedial works arising from engineering decisions
- Litigation payments as a result of their work affecting 3rd parties.
- Avoided loss of revenue by highway operators.

5.3.1 Time saved on Projects

We have established that, by detecting problems earlier through the use of InSAR, some delays to projects can be avoided so saving time for both ANAS and the construction teams. In section 5.2.4, we calculated a benefit of €0.5m to €1m for ANAS coming from a weekly cost of €20k for each of between 25 and 50 concurrent projects.

We shall assume the same scale of benefits for the construction teams even though, as they will have equipment deployed to the sites (which ANAS does not), their weekly costs are likely to be higher. As a result, we shall include a total benefit of €0.5m to €1m under tier 3.

5.3.2 Avoided cost of remedial works

This is less obvious in terms of benefits. For ANAS, it is clear, getting the design right avoids a lot of problems and remedial work and cost later. However, for the construction team, which is working for ANAS, unless the delay is caused by their own decisions, any additional costs should be covered by the contract and hence paid by ANAS.

Hence, we consider that the cost of remedial work has been covered in our analysis for ANAS and we shall not add additional benefits under this tier.

5.3.3 Litigation costs as a result of 3rd parties

The companies themselves can also benefit from the use of the InSAR maps to avoid litigation costs. We discussed this earlier in relation to the Basilicata viaduct where a dispute arose between ANAS and their engineering contractor over some underground movements. This was resolved amicably but knowing when a movement has taken place and if it is continuing is critical information associated with construction works.

We talked (for another case) with one international construction company which had used Sentinel derived InSAR maps to support its defence against litigation. They had executed a large re-development project but directly adjacent to a building which had another owner. This owner had claimed damages as a result of the reconstruction. In this case, the InSAR maps from Sentinels did not offer sufficient spatial resolution to give adequate proof of movement (or lack thereof) of the other owners' building. Using higher resolution commercial data may have offered sufficient evidence, but this data was not available from the archive for the period in question.

This risk applies mostly in built-up areas where highways construction may impact on other businesses, infrastructure operators (railways for example), commercial centres or private housing. In each case, high precision measurements are required to have any possibility to distinguish the location of movement with sufficient accuracy for a court of law. Even if Sentinel data does not offer sufficient spatial resolution, the availability of measurements which show when movement occurred may support a legal case. For this analysis, we shall ignore the potential benefit from avoiding litigation but are largely convinced that InSAR maps have a role to play here in the future.

5.3.4 Avoided loss of Highway revenue by Operators

Losses may arise due to a delay in the opening of the road or of it being closed due to unforeseen ground movement. We consider that benefits for avoiding the former are included in the other categories and will focus here on delays occurring due to the road being closed due to some form of ground movement.

Delays to projects will also cause loss of revenue for the road operator either through the loss of direct toll fees, or concession fees flowing from the government. Since it would be difficult to establish a toll fee linked to a specific road closure, we shall take a more generic approach by looking at a number of different examples and ways of calculating an effective loss resulting from a closure. Note that in the following text, we refer to this effective loss as a cost.

- ANAS has an annual budget of around €3b. As a simple rule of thumb, the overall benefit from this investment should be double ie invest €3b to gain €6b. Let's assume this is amortised over 20 years, this yields an annual benefit of €300m which for 50 projects is €6m per project or €120k per project per week.
- In order to validate these assumptions, we looked at other studies on related subjects. In a study conducted in Scotland[44] around several incidents of road closures, costs due to delays have been calculated of between €70k and €100k per day. Full closure costs came out much higher than this, hence these numbers seem rather conservative.
- Another study[45] in the US (Washington State) analysed the costs associated with a road closure due to a major flood event. The authors examined the potential impact of a major (100 year) flood event on traffic flows. They concluded that if the Interstate 5 highway was closed for 123 hours, the cost would be around $11.5m in total or €2m per day. Less-used roads would cost less i.e. US12 would cost $340k for a 6 days closure and the state road 6 would cost $114k for a 2-day closure.
- Finally, the European Roads Federation in its report published in 2017 on the socio-economic benefits of roads[46], reports that the European Investment Bank considers that a majority of road projects offer a return on investment of 13% or more. Applying this to the ANAS budget of €3b, spread over 60 projects, yields a figure of €125k per week as the value.

For our analysis, we shall use the rather conservative figure of €100k per week as the socio-economic cost / loss of a road being out of service.

Let us assume that around 20% of this loss is felt by the road operator – which also represents a cost to the road users. In other words, €20k per week is lost revenue for the operator and €80k per week is a social loss distributed widely amongst the users of the road. We postulated a figure of between 25 and 50 project weeks of delays throughout the ANAS network which could be mediated through the use of InSAR maps. This leads us to calculate a revenue loss of €0.5m to €1m for the road operator.

Note that the remainder of the social cost (ie €80k) will be attributed under Tier 4 as a loss of benefit to the wider society.

5.3.5 A few words on Landslides

Whilst landslides may arise through slippage over time or be caused as a direct result of seismic activity they can also be triggered by heavy rain. When they do, they can cause road closures and heavy disruption of traffic (see box). Can the use of InSAR help to mitigate their impact and what may be the benefits?

[44] The economic impact of landslides and floods on the road network, Winter et al, Advances in Transportation Geotechnics, Volume 143, 2016
[45] Travel costs associated with flood closures in Washington state.
[46] The Socio-economic benefits of Roads in Europe, European Roads Federation, November 2017.

Where slippage has occurred beforehand, then an InSAR generated ground motion map may detect it. This will to an extent depend upon the nature of the vegetation or soil/rocks which cover the slope at risk. Earlier slippages may well expose edges of cracks where the slope is separating and hence there will be a good possibility of detection. Many other parameters come into play such as the orientation of the slope to the satellite overpass but, a recent paper[47] has shown that, by observing the slope over a period, the rate of movement can be used to predict when the failure will occur with a good degree of accuracy. Where slippage is known or suspected, corner reflectors can be deployed which will allow precise monitoring of the slope.

In the European project, LAMPRE9 mentioned earlier, researchers examined the impacts of landslides. Findings from the LAMPRE project9 can help estimate the benefits concerning early detection of landslips.

The main cause which was examined in the study is flooding causing the land to slip. The land may be unstable before the flooding which then exacerbated the movement. In this case, the potential problem could possibly be detected before the catastrophic slip occurs through the use of the satellite-derived, ground movement maps.

The LAMPRE study considered the impact of landslides caused by a major flood on 5 main roads. The cost for fixing them totalled €26,140,736, corresponding to an average cost per road of €5,228,147 and per kilometre of €2,043,841.

How many landslips are occurring each year or how many kilometres of road are affected? Rain is likely to be a factor in most of not all landslips hence, in the absence of other information, we can realistically base the analysis on the findings of the project. In this case, our assumption is that 10 catastrophic slips occur each year– but we make no assumption about the length of the road affected. How much of the effects could have been prevented? Not all will be avoided through the use of InSAR but let's make an assumption that half of them could be.

Landslide on the A6 highway at Savona

The landslide which occurred at Savona in November 2019 damaged one pillar of the motorway between Genoa and Turin and caused the road to be closed for 3 weeks. In a way, fortunately, the road is split at this point (see Figure 2-2) which reduced the impact of the accident.

Full repairs took several months and the cost of the accident includes the repairs cost as well as the loss of utility for the thousands of drivers using the road each day.

Could this have been mitigated by the use of InSAR? The landslide was provoked by heavy rain but would some slippage have been visible beforehand causing closer surveillance on the hillside and possible preventative measures to have been applied?

[47]perspectives on the prediction of catastrophic slope failures from satellite inSAR, tommaso carlà 1, emanuele intrieri1, federico Raspini1, federica Bardi2, paolo farina2, Alessandro ferretti3, Davide colombo3, fabrizio novali3 & nicola casagli, published in Nature, November 2019.

The effects fall into 2 categories; the cost of the remedial work and the cost of the disturbance to traffic flows caused by road closures. For the latter, the impacts will be much less than during the construction as the duration is assumed to be less.

Generally speaking, the first works after the event are to stabilise the situation, reduce any danger and reopen the road. If we assume that this takes 1 week on average then, based on the earlier calculation of the lost benefit costs as a result of traffic disturbances (€100k per week), we arrive at a total value of €0.5m per annum.

For the remedial works, the costs are given above and dominate the disturbance (loss-of-use) costs. From the study, we start with an annual cost of remedial works due to landslips due to flooding of €26.1m per annum. We make an assumption that the remedial costs may be reduced by 20% if the remedial work can be undertaken before the catastrophic slide occurs. Based on a total annual cost of €26m this leads to a potential saving of €5.2m.

However, the possibility for InSAR to detect early movement even if it occurs is not proven. We make the above calculation as a way to reinforce the arguments for the benefits but at this stage, we shall not include these numbers in our final analysis.

5.3.6 Overall Benefits for Tier 3

The overall benefits for Tier3, the construction industry and highway operators are shown in the Table below.

	Minimum	Maximum
Construction sector	€0.5m	€1m
Highway Operators	€0.5m	€1m
Total Benefit	€1m	€2m

Table 5-5: Economic Benefits to Tier 3 actors

5.4 Citizens and Society (Tier 4)

The construction of new roads, or the improvements made to existing ones, are designed to improve the flow of traffic and avoid congestion. De facto, any delays to the opening or closures of the road once opened have a negative impact on the users of the roads ie citizens and freight moving people and goods. Hence, avoiding these closures benefits the general public and the transport industry due to avoiding time lost on their journeys.

It then follows that, if the use of InSAR can lead to earlier opening of roads under construction or the avoidance of closure due to the need for remedial works caused by ground movement, this leads to a direct benefit for the citizens and society at large. The benefit represents the value of the time which is saved through avoiding closures and diversions of the traffic.

We have earlier calculated a societal value of €100k on average for each week of road closure. Clearly, this number varies enormously according to the location of the road and the volume of traffic it carries. Nevertheless, whilst a busy highway may be carrying many people and goods cannot be directly compared to a minor road serving a hillside village, the direct economic cost of the former may not be so different from the severe inconvenience and hence high societal cost for the latter.

We can also note the reference made earlier to cost estimates made for the loss of the utility of the Morandi bridge. ISORT claimed that the cost to haulage operators alone was around €600k per day and that this rose to €2m per day considering all road users. This is certainly at the high end of the range of costs and suggests that our value of €100k per week is not unreasonable.

In order to calculate an economic cost, we shall make some simple assumptions which are shown in Table 5-6.Independent of the approach used, the net result is a minimum of 8 weeks of road closure avoided by the use of InSAR up to a maximum of 30 weeks. Note this may be caused by 8 different roads each not-closed for 1 week, or 56 roads each not-closed for 1 day – or indeed any combination thereof.

Parameter	Minimum		Maximum
Average societal cost of a road being out of use per week	€100k		€100k
Number of projects which are impacted by ground movement each year	2		5
Average duration of remedial works ie project delay	4 weeks		6 weeks
Total opportunity benefit due to reduced loss-of-use associated with delays to projects (reduced delays by the use of ground movement monitoring maps)	€0.8m		€3m

Table 5-6: Societal Benefits arising through avoided road closures.

The final results seem quite modest but recalling that we are attributing these 100% to the use of satellite Sentinel data and that many road closures are due to factors unconcerned with ground or slope instabilities.

5.5 Other Stakeholders

Whilst there are many stakeholders in the case of road infrastructure and we have identified some in chapter 4, none are directly impacted as a result of the use of InSAR maps. ANAS represents the Italian government and indeed the Italian state in the process. There do not appear to be many environmental considerations coming from the use of the satellite data.

On the other hand, other departments or other public policies may benefit in other ways which we have seen in other cases, as a result of using InSAR. Examples are the updating of building regulations accounting for ground movement, which can be measured and can lead to restrictions on building in affected areas. More directly, linked to road construction, the responsibility of contractors to avoid consequent damage as a result of the works can be better protected as measurement of the impact is possible. This can lead to better legal protection for other 3rd parties as well as between the state and the industry.

5.6 Summary of the Benefits

The overall benefits, deriving from the use of ground movement maps, across the tiers and allowing for minimum and maximum assumptions are described in the various categories of benefits[48].

The subjective assessment of the benefits coming from the use of Sentinels' data for highways management in Italy is shown in Table 5-7.

Economic	Environmental	Societal	Regulatory	Innovation & Enterprise	Scientific & Technological
★★★★		★★	★	★★★	★★★

Table 5-7: Benefits Assessment by Category

5.6.1 Economic Benefits

Given the dominant role of ANAS in the creation and maintenance of the Italian highways network, it is perhaps unsurprising that the majority of benefits in the value chain fall either with ANAS or with the citizens. Table 5-8 below, shows the summary total of the estimated economic benefits along the value chain.

	Minimum	Maximum
Tier 1 – Service Provider (Planetek)	n/a	n/a
Tier 2 – Primary User (ANAS)	€3.8m	€8.6m
Tier 3 – Construction Companies & Highway operators	€1.0m	€2.0m
Tier 4 – Citizens and Society	€0.8m	€3.0m
Total	€5.6m	€13.6m

Table 5-8: Economic benefits along the value chain

The indicators which have been used to calculate these benefits are:

- Reduced survey costs for ANAS in tier 2 by the use of the Rheticus product and avoiding the need for multiple traditional surveys.
- Reduced cost of remedial works by being better informed of the slope instability, a more secure design can be introduced so avoiding the cost of remedial works later in the project.

48 The methodology has been updated during the SeBS project to address benefits going beyond economic and environmental. See description in Annex 2.

- Time can be saved on the project by avoiding the later discovery of issues connected with slope instability so avoiding project delays
- Reduced litigation cost through having a more precise diagnostic of where and when ground movement has taken place.
- Reduced loss of use of the highway.

- Reduced costs of surveys and of remedial works (Tier 2)
- Reduced project delays
- Reduced litigation costs by more precise measurements of location and in time.
- Reduced amenity loss for citizens avoiding road closures.

5.6.2 Environmental Benefits

Roads are considered as having a high impact on the environment both through the loss of countryside and possible impact on the natural habitat as well as leading to increased use of motor vehicles and hence higher carbon emissions. To the extent that the InSAR maps may help deliver more efficient highways management, there could be considered a small consequential impact on the environment.

Elsewhere, we have come across situations where the construction of a tunnel can lead to changes in underground water flows and aquifer levels. In this respect, periodic monitoring using InSAR could help identify and maybe even help mitigate any impact on, for example, local farms. There is no reason why this should not apply in Italy as well and for this reason we consider it a latent or potential benefit but with only a small environmental impact of the use of InSAR maps as described in this case.

5.6.3 Regulatory (Policy related) benefits

Regulatory impacts are those where the use of satellite-based technology can lead to better policy development and or implementation. Whilst analysing this case in Italy, we did not come across any specific actions or ideas relating to regulatory matters. There was however a strong interest expressed in monitoring bridges which was even before the Morandi bridge collapse.

Nevertheless, there are a number of areas where knowledge of ground movement can lead to better regulation. Simply the ability to measure the movement and to track it over time allows both a better understanding of what may be causing the movement and when it is happening. As in a SeBS case in Spain[49], or more specifically a similar case to this one in Norway[50], more precise and large-scale measurements can enable limits and conditions to be built into regulations which would otherwise not be possible.

A time series of ground motion data combined with other data can enable forecasts to be made. This can be critical for long term effects. Where ANAS or the construction engineers may be

[49] Aquifer management in Spain, SeBS case to be published.
[50] Ground Motion Monitoring in Norway; SeBS case, July 2020

responsible for any consequential damage, this can now be quantified more easily through the use of InSAR. Knowing when any movement occurred is strong evidence in any litigation.

Given the above, we consider there is a latent potential to improve regulations in Italy.

- Better regulations: the ability formulate better regulations knowing that EO services can provide a monitoring tool including limits on regulated values.

5.6.4 Innovation and Enterprise Benefits

This category of benefit is linked to the contribution the use of the satellite-based technology has on innovation and entrepreneurship on the players in the value-chain. Here we consider that the benefit is quite significant. Certainly, the impact on the service provider, Planetek, is high both in stimulating innovation and the development of the Rheticus service as well as creating highly skilled jobs in the sector.

ANAS also benefits through the use of new and novel techniques as part of its standard operating procedures along with the potential to change other parts of the organization i.e for bridge and tunnel monitoring and for possible landslips.

We consider that the benefit is manifest and high for its impact on Planetek but also on the use of ground movement surveys throughout ANAS.

- Improved business processes.

5.6.5 Scientific and Technological Benefits

There are few scientific and/or technology benefits coming from the service. However, there is some potential for changes to processing chains and data flows as a result of new technology being applied to the generation of the Rheticus service.

The service itself is also useful for further research. Its use for monitoring unstable hillsides and potential sites of landslides, the use to monitor the stability of bridges and stresses building up in structures are just two of the immediate examples. Others abound as we have seen in other cases concerned with pipelines monitoring and aquifer monitoring. Hence the potential of the technology is high.

Some of these changes apply to roads management and ANAS. Potential changes in ANAS processes of this nature are manifest and overall, we consider that this category of benefit is moderately important for this case.

- Contribution to research into new applications (and processes linked to highways management)

5.6.6 Societal Benefits

Societal benefits are recognized in tier 4 of the value-chain which considers that a reduction in time to complete a project and avoiding time where a road is closed both have direct benefits for society. These arise through less time lost in travelling both as individual citizens and for freight carriers. The overall societal benefits are manifest in the case but are low considering the travel disruption as a whole across Italy due to other causes.

- Improvements in the use of public infrastructure

6 Conclusions

6.1 Summary of Findings

The wide availability and frequent coverage of Sentinel-1 SAR data is transforming the use of InSAR for many applications with road construction being one of the foremost. Those companies responsible for the management of a country's highways are starting to appreciate the potential that InSAR technology offers and are starting to introduce its use into their projects. Other methods to measure vertical ground motion (or subsidence) are either more expensive or limited in quality and the area that can be monitored.

Consequently, surveying sites for movement of the ground becomes possible and can be used more widely than for just risky projects. As a result, earlier detection of problems can lead to earlier mitigation measures leading to savings of time and less expenditure for remedial works.

We have identified 4 projects managed by ANAS which either have or could have benefited from the use of InSAR should it have been available in the early stages. In 2 cases, the planning and design would have been easier had existing ground movements been known. In one project, severe problems showed up when the project was well into its construction phase which are leading to very high additional costs, and which could have been largely avoided if InSAR measurements had been available for the design. One further project had problems triggered by the construction work which could have been detected and resolved earlier if InSAR measurements had been used.

As a result, ANAS has introduced the requirement to use InSAR monitoring into a number of new projects.

In our analysis, we estimate a possible economic benefit to ANAS of between €6m and €14m per annum with further benefits to the road users through reduced road closures and reduced delays around consequential road works. We consider that these numbers are very conservative, and it will be interesting to revisit them in several years' time.

InSAR mapping is a new technology and there are other ways in which its use is, or potentially can, benefit the people of Italy by:

- promoting innovation within ANAS, engineering and construction companies and other actors engaged in the management of highways.
- encouraging entrepreneurship in Planetek and other companies to supply new services
- reducing traffic disruption due to delayed projects and problems with roads, tunnels and bridges
- enabling better legislation including responsibilities for co-lateral damage during engineering works.

On the other hand, we do not consider that there is a strong environmental benefit coming from its use.

Each case we look at within the SeBS work has its own peculiarities. This makes these analyses especially interesting and comparisons between similar ones very rich. The responsibility of ANAS as the national road's agency and the governance of the roads in Italy, has two consequences for the case:

1. Applications are generally in less populated areas and away from urban conglomerations. where the use of Sentinel-1 data will be more effective. (In urban areas, higher-resolution, commercial data will be needed more frequently).
2. More of the benefits are felt by ANAS (tier 2) for planning and design, as well as the citizens (tier 4) which ANAS is serving i.e. the road users.

6.2 The Impact of Sentinel Data

Sentinel data is having a huge impact on the use of InSAR. The free data makes full, country-wide processing possible, and, for many applications, the precision offered by higher resolution is not necessary. The frequent coverage allows ground motion maps to be generated every 10 to 20 days on a routine basis. A combination of country-wide maps once per year and on-demand maps for specific areas would seem to offer the best combination.

For roads and highways management, this is providing a new tool with a capability not available previously. The wide coverage allows large areas to be surveyed for movement at a relatively low cost. The high precision at mm accuracy allows very small movements to be detected. The ability to cover the country each year, allows historical data to be examined for newly designated highway routes.

The capability of radar satellites to measure the vertical movements of points on the ground to a high precision with mm accuracy, has many applications. These are being identified and explored further fueled by the free and open data coming from the Sentinel-1 satellites. Whilst some uses require precise locations as well as movement, many uses including those discussed in this report are satisfied with knowing that there is ground movement without knowing its location to better than a few meters on the ground.

6.3 Widening the Perspective

Road highways exist all around the world and ground movement can arise under many different geological conditions. The principles of detecting and measuring ground movements and their impact on roads can be extended globally. Social conditions, the extent of the road network, the density of use change between countries so the scale of the benefit is different in each case.

The case looks at InSAR use for monitoring non-urban road conditions. The principles can also be extended to urban areas, but the higher density will likely require the use of higher resolution radar data even if the movement itself can still be detected using S-1 data. Hence, we can develop the picture of S-1 data being used for detection of movement whilst commercial, high-resolution data is used to locate the movement.

Whilst in Italy we have considered mainly the risk of damage to roads through seismic activity and landslides, other geological conditions can also give rise to problems. In the Netherlands, we looked at the effect of clay soils and the impact on buried pipelines. Sub-surface movement can also cause road failures especially at critical points of bridges and tunnels.

In Norway, we have looked at the impact of moraines caused by ancient glaciers and the damage they can cause as they move. All this is to say that the technique may be applied in many different countries having different geological conditions, but any of which can lead to surface movements and road damage.

We touched upon the ability of InSAR to monitor bridges. Indeed, this topic was brought up even before the Morandi bridge collapse. Where instability is caused by ground movement, then the situation is clear but in the case of the Morandi bridge this was not the case. There is some evidence to suggest that movement of the bridge itself could be detected without being able to designate any cause. Such a detection could be used as a trigger for further investigation. This is surely being considered by road agencies and engineers, but it may not be the best technology for this application.

6.4 Some Final Thoughts

This case has proven really interesting but difficult to analyse with the work spread out over nearly 3 years. The first meetings took place in autumn 2017 and progress was intermittent. In effect, we started to embark upon it before the use of the service had become embedded in the operational processes. The same is true for the case we have analysed in Norway but starting it 2 years later meant that it was more mature.

This lesson served to underline one of our golden rules for the selection of cases, that it should be used operationally within the "primary user" organisation. In the case of Sentinel data use for highways management in Italy, Norway or elsewhere this is still early days. Nevertheless, the cases show the extremely strong potential for the use of InSAR for roads management. The findings in both Italian and Norway cases are strong, and we find unique uses for InSAR in both countries. This will surely extend to others.

The case does highlight the potential for InSAR to play a strong role in highways management whether in Italy or elsewhere. We placed some emphasis on the geological instability of Italy which gives rise to earthquakes and tremors. Whilst other countries are more stable in this sense, other geological factors also cause ground movement as we have already seen in the pipelines case in the Netherlands and are addressing in further cases in Norway and in Spain. The potential to monitor fixed infrastructure such as bridges and tunnels appears to be strong; but will require commercial data since the spatial resolution of Sentinel-1 is insufficient to locate the sources of movement. This is also true for litigation where the source of the movement will need to be identified. However, Sentinel-1 can trigger an activation of a higher resolution satellite, so the service still has considerable value.

But for the core case of detecting where movement is impacting on infrastructure projects, this case shows how this can be valued and the contribution it may make. ANAS has already recognized that the value is there for them by incorporating the use of InSAR monitoring as a requirement in recent tenders; the InSAR will be used alongside other methods whilst it is being fully understood by ANAS experts.

As a result, it will be interesting to return to this application in the future. The potential for the use of InSAR for highways management is very strong. As experience is developed within the road's management authority so more use cases will be available to refine the analysis. This can be especially so for bridges and tunnels but should also be explored further for landslides.

We have also explored in a limited way, how climate change may impact on roads management. The changes in environmental conditions whether of temperature, rainfall, or the frequency and energetic amplification of extreme events, will need to be taken into account in the future design of roads. Having more tools to understand those conditions at the local level will be an advantage in understanding design limits and monitoring for excess stress. It is difficult to predict the outcome – as difficult as it is to predict precise changes in the local environment –but satellite data such as InSAR can help.

In conclusion, despite the difficulties, this has been a very interesting case to analyse. It is already one of a portfolio looking at the value of InSAR technologies and we expect this to be even further extended in the future. Similarly, at least one further case looking at highways management is anticipated and the portfolio effect i.e. where similar cases are studied in different value-chains and in different legislations (countries) should be developed further.

Annex 1: References and Sources

Here is a list of the major external documents and reports used and referenced in the case. These are compiled as the “Specific Manual” for the case.

1. European Road Federation; Road Statistics.
2. Impact of Event Landslides on road networks; Donnini et al, Landslides 2017.
3. Travel costs associated with flood closures of state highways in Washington state; September 2014.
4. National Funding of Road Infrastructure in Italy.
5. The Economic Importance of the National Highway System, Keane
6. Highways in Numbers; Italian Association for Motorway operators (AISCAT),
7. The Socio-economic benefits of roads in Europe, International Roads Federation, November 2007.
8. Road infrastructure cost and revenue in Europe; IMPACT, Claus Doll (Fraunhofer Inst, Huib van Essen (CE Delft)
9. Pre-collapse space observations of critical infrastructure: The Morandi bridge; Pietro Milillo, Giorgia Giardina, et al.
10. Remote Sensing as a tool for developing a landslide database (LAMPRE project). August 2014.
11. Environmental Impacts of better roads; SINTEF 2007. (English summary) Report A07034
12. Atlantia Group Profile - 2017
13. Cost-benefit analysis of a proactive geotechnical asset management.; Michegan Technological University. Rudiger Escobar Wolf et al.
14. The social rate of return on infrastructure investments; World Bank Research Group, policy research paper, July 2000
15. Landslides in a Changing Environment; Gariano & Guzetti (CNR)
16. Earthquake Bulletin; Italian national institute for volcanology
17. The economic impact of landslides and floods on the road network, Winter et al, Advances in Transportation Geotechnics, Volume 143, 2016.
18. Understanding the Impact of Transportation on Economic Development, Randall Eberts, Minnesota Department of Transportation.
19. Perspectives on the prediction of catastrophic slope failures from satellite inSAR, tommaso carlà 1, emanuele intrieri1, federico Raspini1, federica Bardi2, paolo farina2, Alessandro ferretti3, Davide colombo3, fabrizio novali3 & nicola casagli, Nature November 2019

Annex 2: Glossary of Abbreviations

ANAS - Azienda Nazionale Autonoma delle Strade

BI – Business Intelligence

DSS – Decision Support System

GMES – Global Monitoring for Environment and Security

InSAR – Interferometric SAR

LAMPRE – Landslide Modelling and tools for vulnerability assessment, Preparedness and Recovery management.

MIMS - Ministry of Sustainable Infrastructure and Mobility

MTI – Multi-Temporal Interferometry

SAR – Synthetic Aperture Radar

SeBS – Sentinel Benefits Studies

TREN – Trans European Networks

Annex 3: General Approach and Methodology

This case has been analysed as a part of the Sentinel Benefits Study (SeBS), which looks at the value being created by the use of Sentinel data. It follows a methodology[51], established during a previous study, looking at a value chain for the use of a single EO service.

For each case, a value chain is established with a service provider and a primary user. The value-chain is validated with these two key players. Through a combination of desk and field research, we develop our understanding of all the actors in the value chain, the role that they play and how they may benefit through the use of the satellite-derived products.

The value-chain is divided into a number of tiers where the supplier is Tier 1, and the primary user is Tier 2. The last Tier is always "Citizens and Society". The number may vary according to the complexity of the value-chain. The benefits are then analysed against each of these tiers.

Once written, the draft report is then shared with all the persons with whom we have spoken, and their comments are incorporated, or a further discussion is held to establish a common understanding. Note that we are not asking these experts to endorse our findings but to indicate any gross errors or sensitivities which may have been introduced. At the end of this process, the report is made public.

As work has proceeded and more cases analysed, some modifications have been made to the methodology described in reference 51. The first of these has been to expand from the two dimensions used earlier, namely economic and environmental benefits, to add those connected to societal, regulatory, innovation and entrepreneurship and scientific and technological. These six dimensions are described in the table A2-1 below.

Dimension	Definition
ECONOMIC	Impacts related to the production of goods or services, or impacts on monetary flow or volume, such as revenue, profit, capital and (indirectly, through turnover generation) employment.
ENVIRONMENTAL	Impacts related to the state and health of the environment, particularly as regards the ecosystem services on which human societies depend.
SOCIETAL	Impacts related to societal aspects such as increased trust in authorities, better public health or secured geostrategic position.
REGULATORY	Impacts linked to the development, enactment or enforcement of regulations, directives and other legal instruments by policymakers.
INNOVATION-ENTREPRENEURSHIP	Impacts linked to the development of new enterprise and/or the introduction of technological innovation into the market.
SCIENCE-TECHNOLOGY	Impacts linked to academic, scientific or technological research and development, the advancement of the state of knowledge in a particular domain.

Table A2-1: Definitions for the benefit dimensions

[51] SeBS Methodology; June 2017.

For each of these, a ranking has been introduced to give an immediate, visual impression of the scale of the benefits under each dimension. To aid in the quantification of these, a guide has been introduced which is shown in Table A2-2.

Rank	Benefit status	Criteria
0	**Null**	The case presents no perceivable benefits in this dimension, and no potential for such benefits to emerge is anticipated.
1	**Latent**	The value chain described in the case may, in general, present potential benefits in this dimension, but none have been identified or described in this particular instance.
2	**Manifest**: At least one benefit in this dimension has been identified through the value chain within the case. Its significance in the context of the case overall is judged to be:	**Low**
3		**Moderate**
4		**High**
5		**Exceptional**

Table A2-2: The ranking of the benefits.

In order to introduce further basis for comparison, a systematic approach has been developed for the analysis of the benefits. A series of indicators have been defined for each of the benefit dimensions against which each case can be considered.

The indicators used in the case are listed in section **Error! Reference source not found.**, and a full l ist of all indicators considered is provided in Table A2-3.

Dimension	Indicator	What it can mean.
Economic	Avoided costs (AV)	Alternative means to gather data
	Increased Revenues (IR)	Increased production/sales
	Reduced Inputs (RI)	Less time spent or material saved
	Improved Efficiency (IE)	Better use of resources
Environmental	Reduced pollution (RP)	Reduced amounts of pollutants in key resources e.g. water, air
	Reduced impact on natural resources (RR)	Reduced environmental impact e.g erosion, habitats/biodiversity.
Societal	Improved public health (IPH)	Less toxicological risk
	Common Understanding (CU)	Better control and communication of remedial efforts i.e through common maps.
	Increased trust and better transparency (ITT)	Improved preparedness / response
	Strategic Value (SV)	Common societal value to a country or region.
Regulatory	Improved policy / regulation design/drafting	Better information (scale, accuracy) leading to better regulation
	Improved efficiency in policy/regulation monitoring	Better information available to monitor adherence to regulations.
Innovation & Entrepreneurship	Innovative products	Sentinel data leads to creation of new products / services
	New Business models	New ways to generate income.
	New markets	Global nature of sentinel data enables international business development
	New businesses	Creation of new companies; start-ups
Science & technology	Academic output	
	Research exploitation	Applied science to operational services
	Research contribution	New product enabling scientific research

Table A2-3: Complete list of indicators considered within SeBS analyses.

Annex 4: Winners… and losers?

The creation and subsequent usage of Sentinel data down the value chain has a significant economic impact. Quite prominently, product and process innovation based on the availability and subsequent application of the data, lead to positive effects where new products and services emerge, and existing processes can be run more effectively and efficiently. Conversely of course, there are also consequences on some of the previous beneficiaries. For instance, revenues might be shifted, and jobs displaced and sometimes even destroyed, creating technological unemployment. In the current study, for example, some workforce might have been lost in reducing the site inspections while savings from farmers certainly translates into loss of revenues for the agro-chemical industry.

> As we have shown in our study 'Winter navigation in the Baltics' as the captains on the icebreakers in the Baltics could suddenly rely on Sentinel based ice charts providing a fully synoptic picture of the ice, the helicopter pilots they traditionally relied upon, became abundant.[52] Similarly, in our study 'Forest Management in Sweden' the Swedish Forest Agency could reduce the number of forest inspectors, as Sentinel data allowed for a reduction of in situ inspections.[53]

How technological progress and innovation are related to employment has been an area of fierce debate for centuries. From fairly recent studies appear that product innovation spark new economic activities, creating new sectors, more jobs, whereas process innovation[54] is more job destroying, although market mechanisms can sometimes largely compensate for the direct job losses, mitigating the ultimate impact on demand for labour. Such price and income compensations can derive from a decrease in wages, leading to an increase in demand for labour or the effects of new investments (enabled by accumulated savings) creating new jobs elsewhere. Obviously, the speed and impact of such effects are highly dependent on the flexibility of markets, the level of competition, demand elasticity, the extent of substitutability between capital and labour and, of course, possible institutional rigidity.[55]

> A German study on the co-evolution of R&D expenditures, patents, and employment in four manufacturing sectors concluded that patents and employment are positively and significantly correlated in two high-tech sectors (medical and optical equipment and electrics and electronics) but not in the other two more traditional sectors (chemicals and transport equipment).[56] Similarly, a study using a panel database covering 677 European manufacturing and service firms over 19 years

---

[52]Sawyer, G. and De Vries, M. "Winter navigation in the Baltics." Copernicus Sentinels' Products Economic Value: A Case Study (2015)

[53]Sawyer, G. and De Vries, M. "Forest Management in Sweden." Copernicus Sentinels' Products Economic Value: A Case Study (2016)

[54]As process innovation is defined as producing the same amount of output with less labour (and sometimes other) inputs, logically the direct impact of process innovation is job destruction when output is fixed.

[55]Vivarelli, M. "Innovation and employment: Technological unemployment is not inevitable—some innovation creates jobs, and some job destruction can be avoided." IZA World of Labor 2015: 154

[56]Buerger, M., T. Broekel, and A. Coad. "Regional dynamics of innovation: Investigating the coevolution of patents, research and development (R&D), and employment." Regional Studies 46:5 (2012): 565–582.

(1990–2008) detected a positive and significant employment impact of R&D expenditures only in services and high-tech manufacturing but not in the more traditional manufacturing sectors.[57] Another study found a small but significant positive link between a firm's gross investment in innovation and its employment based on longitudinal data set of 575 Italian manufacturing firms over 1992–1997.[58]

Clearly, this tells us that the ultimate 'net' impact of innovation – both at product and process level - brought about by the availability of new technology, such as Sentinel data, will be closely related to the market and institutional settings in which they become effective. However, on the whole the conclusion seems justified that the 'negative' effects, in the form of possible loss of employment, is largely outweighed by the positive economic effects throughout the value chain.

Accordingly, in this study – and likewise for the past and future ones - we will concentrate on the positive effects brought about by the availability of the Sentinel data throughout the value chain. That there are also (temporary) 'negative' impacts is a given, but the net effect at macro level will always be positive.

[57]Bogliacino, F., M. Piva, and M. Vivarelli. "R&D and employment: An application of the LSDVC estimator using European data." Economics Letters 116:1 (2012): 56–59.

[58] Vivarelli, M. "Innovation, employment, and skills in advanced and developing countries: A survey of the economic literature." Journal of Economic Issues 48:1 (2014): 123–154 as well as "Technology, employment, and skills: An interpretative framework." Eurasian Business Review 3:1 (2013): 66–89.

Annex 4: InSAR and its applications

Since 2000, several MTI approaches have been proposed, all aimed at extracting accurate displacement measurements in the SAR scene by facing the two most important limitations of SAR interferometry: the decorrelation due to ground cell noise (e.g. vegetation movement and the atmospheric artifacts due to spatial and temporal refractivity index changes).

Both decorrelation and atmospheric artifacts introduce changes in the radar echo of a given target, which in turn “corrupt” the displacement information encoded in the phase return. Typical examples of decorrelation are target in vegetated areas where the ground cell changes its scattering properties from one acquisition to the other due to vegetation growth. Generally in these areas are not available reliable measurements; only the presence of isolate exposed rocks or isolated home-made structures in these areas allow to get some measurements there.

MTI techniques have been introduced in the scientific community in order to (1) estimate (and remove) atmospheric artifacts exploiting its stochastic behavior, which is known to be totally uncorrelated in time but correlated in the space domain with a power-law frequency spectrum, (2) identify coherent targets (through the temporal analysis of their phase residuals) on which (3) accurate position and displacement measurements are extracted.

The MTI algorithms can be grouped into two general categories: those based on Persistent Scatterers, that rely on the phase information from single isolated objects characterized by a high temporal phase stability and those based on small-baseline approaches (known as Small Baseline Subset techniques) that rely on the use of distributed scatterers (DS) where there are no dominant elements within the resolution cell.

More specifically, multi-temporal SAR techniques play an important role since they are based on the identification of coherent targets on the ground whose reflectivity is sufficiently independent from both the temporal and the geometric baseline. In particular, these techniques make a distinction between Persistent Scatterers (PS) associated with a single pixel of the radar image and the Distributed Scatterers (DS) that are associated with a group of statistically homogeneus pixels of the radar image. The use of groups of pixels in the case of DS, is dictated by the need to operate spatial averages between adjacent pixels of the same nature in order to reduce the presence of noise. On the contrary, in the case of the PS, the target inside the single pixel is sufficiently dominant with regard to the noise and therefore it is not necessary to further improve the quality of the phase response; this also allows to preserve the maximum spatial resolution of the target itself. In the case of DS, instead, spatial average operations introduce an unavoidable spatial resolution loss compared to the native resolution of the radar image.

In short, PS and DS represent points (PS) or areas (DS) with high phase stability (or equivalently high coherence), thanks to which it is possible to monitor a zone (in which they are present) even for a long period of time and taking advantage of the whole set of images available, without setting limits to any geometric or temporal baselines.

As a result of the integration of PS and DS, the displacement maps exhibit an improved spatial sampling and consequently allow a better interpretation of investigated deformation phenomena that affect the infrastructures.

When we are dealing with vegetated areas where is not possible to detect natural PS or DS, artificial Corner Reflectors can be installed in order to obtain a reliable measured points thanks to their reflection capability of the radar signal back to the satellite. An important characteristic of the CR is related to the fact that does not require any power source to act as a monitored vertex and it can be easily installed on each specific point of interest guaranteeing reliable new displacement measurements after each new SAR acquisition.

Monitoring examples using SAR satellites for specific thematic applications potentially impacting the transport networks maintenance and safeness are:

- **Displacement monitoring of roads and railways infrastructures**

  The historical and continuous acquisition and processing of SAR data by means of Multi-Temporal Interferometry (MTI) algorithms makes it possible to continuously monitor both the structural motion of roads and railways and the third-party induced displacement that may negatively impact the infrastructures. These information represent a fundamental information for the infrastructures operators that is able to trigger preventive and mitigation actions in order to reduce the risks related to natural or anthropic events that may affect the infrastructures.

- **Flood mapping**

  Data acquired from satellite based Synthetic Aperture Radar systems, such as Sentinel-1, with their ability to penetrate cloud coverage are also very useful to evaluate the extent of flooding events especially during or soon after the storms, when cloud coverage usually doesn't allow the use of optical data. SAR sensors have very low return from water bodies making them an ideal tool for mapping flood extents. In a radar image, the delineation between water and non-water can be clearly delineated.

  Mapping of this nature has obvious applications in flood risk management and planning. It can assist engineers and planners of roads and infrastructures make more informed decisions and so help reduce the risk from future floods. In addition, the fast turnaround possible between the data being acquired to the flood extents being produced means these maps could assist emergency services during a flood event.

In addition to SAR satellite technology, data acquired from optical remote sensing can have a great value for monitoring different natural or anthropic phenomena that can have potential impacts on transport networks maintenance and safeness.

In general, a change detection application could support in different ways the identification of specific locations that need maintenance and/or where safeness issues may arise due to some variations from the standard situation.

Change detection algorithms applied to the optical data may be of different nature according to the targeted objects, and of course the spatial and temporal resolution of the input data determines the size of what can be "detected" and the phenomenon that can be "monitored".

If we refer to the Sentinel-2 data, which represent today a great opportunity for their provision at no cost and for their revisit time of 3-5 days (depending of the latitude) and a spatial resolution up to 10 meters in the visible and near infrared spectral range, the change detection applications may target different phenomena potentially impacting the transport network.

Sentinel-2 opens a large scale of new applications allowing to continuously monitor changes on the ground over huge area of interest (regional to national scale) highlighting hot spots of changes that, once detected, could be further inspected, if deemed necessary, with greater detail using very high resolution satellite images and visual inspection.

Digital Change Detection algorithms can provide binary land cover “change/no-change” information by automatically detecting the spatial regions within a bi-temporal image pair where meaningful change is likely to have occurred, then a human operator (or another process) can analyse the changes using his/her knowledge.

For change detection, using a pair of images, three main categories of methods could be used:

- Simple Detection: use Mean Difference, Ratio Of Means or Root Mean Square Differences of the relevant bands (typically visible and near infrared bands).
- Normalized index change detections: produce normalized indicators related to the targeted change to be detected (e.g. built-in areas) and compare them.
- Post Classification Comparison: make supervised classification of the pairs and compare results (e.g. land cover comparison, Built-up Areas comparison).

Monitoring examples using optical remote sensing for specific thematic applications potentially impacting the transport networks maintenance and safeness are:

- **Monitoring the evolution of artificial surfaces**

  The automatic detections can generate alerts, that can activate further inspections with other techniques.

- **Monitoring coastal erosion**

  Optical satellite data can be a precious source of information for monitoring coastal erosion and potential connected impacts on transport network infrastructures. Using comparative analysis of more optical images over time, coastal trends in terms of erosion, stability, and advancements can be identified and represented through geospatial indicators which can support decision making for new interventions and works.

Annex 6: About the Authors

Geoff Sawyer, BSc (Electronics), MBA

Geoff is Secretary General of EARSC having held senior management positions in the space industry and numerous representative positions in the UK and Europe. Geoff was the radar systems engineer responsible for the ERS-1 synthetic aperture radar and after many steps was, until 2011, EADS Vice President Corporate Strategist for Space. In addition to his extensive industrial experience, Geoff spent three years working for the European Commission where he was responsible for supporting the creation of the GMES initiative (now Copernicus). geoff.sawyer@earsc.org.

Other Contributors to this study

Nikolay Khabarov, PhD

His expertise is mathematical modelling and optimization under uncertainty. Dr. Khabarov joined IIASA to strengthen the team in charge of quantifying benefits of improved Earth observations. Since then he has been a principal investigator and contributor to a range of research projects focusing on economics of adaptation, estimation of the value of information, disasters modelling, reduction of risks through innovative financial tools. khabarov@iiasa.ac.at

The SeBS Study Team

The SeBS study is conducted by a team of experts under the direction of ESA (the European Space Agency) and led by EARSC (the European Association of Remote Sensing Companies. The team is of a variable geometry and different experts work together on the different cases. The full team and the organisations for whom they work, is shown below.

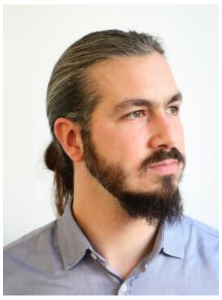
Geoff Sawyer, BSc (Electronics), MBA

Geoff is Secretary General of EARSC having held senior management positions in the space industry and numerous representative positions in the UK and Europe. Geoff was the radar systems engineer responsible for the ERS-1 synthetic aperture radar and after many steps was, until 2011, EADS Vice President Corporate Strategist for Space. In addition to his extensive industrial experience, Geoff spent three years working for the European Commission where he was responsible for supporting the creation of the GMES initiative (now Copernicus). geoff.sawyer@earsc.org.

Lefteris Mamais, MSc in Theoretical Physics

Lefteris is a strategy consultant with solid knowledge of programmatic, strategic and business aspects of EU Space Programmes (Copernicus and Galileo). In the past 10 years, Lefteris has been extensively involved in various studies and projects related to the development, market uptake and exploitation of EO downstream applications. He has been advising clients and partners across the full spectrum of the EO value chain, including EU institutions (EC, EEA, SatCen, ESA), universities and private companies.

lef@earsc.organd lefteris@evenflowconsulting.eu



Dimitrios Papadakis, M.Sc. Research Methods

Dimitrios is a strategy consultant and communication/dissemination expert with over ten years of experience in the commercialisation, uptake and exploitation of space-based data and applications, primarily as concerns the Copernicus programme and its services. He has provided expertise on a range of major market, cost-benefit and user uptake studies in the EO domain, for clients including the EC, ESA, EEA and the SatCen.

dimitri.papadakis@earsc.org and dimitri@evenflowconsulting.eu

Marc de Vries, BSc EC, LLM

Marc has professional degrees in both law and economics (Utrecht 1991). He has been active in the field of Open Data re-use for more than 18 years, both at the national and European levels. Through his company The Green Land he serves clients in the public and private sectors in the Netherlands and beyond (EC institutions in particular). He is a frequent speaker and moderator on Open Data conferences and events. Also he has published various books and articles on PSI, highlighting the legal, economic and policy perspectives. marc@thegreenland.eu.

Nikolay Khabarov, PhD

His expertise is mathematical modelling and optimization under uncertainty. Dr. Khabarov joined IIASA to strengthen the team in charge of quantifying benefits of improved Earth observations. Since then he has been a principal investigator and contributor to a range of research projects focusing on economics of adaptation, estimation of the value of information, disasters modelling, reduction of risks through innovative financial tools. khabarov@iiasa.ac.at

Christopher Oligschläger,

Christopher is an analyst with EARSC. He holds a Bachelor degree in European Studies from Maastricht University and a Double Master's degree in Governance and International Politics from Aston University, UK and Otto-Friedrich-University Bamberg. He gained first work experience (2017) at the Institute for European Politics in Berlin and the OSCE's Conflict Prevention Centre in Vienna before focusing on European space policy and concrete space applications through earth observation. christopher.oligschlaeger@earsc.org.

Dáire Boyle, BEng (Electrical Engineering), MSc Business & Economics

Dáire is a consultant with the Brussels-based consultancy Evenflow, who work in collaboration with EARSC on the Sentinel Benefits Study (SeBS). Dáire worked as an engineer for a large upstream oil & gas company in Aberdeen, Scotland for 4 years before moving to Belgium to complete a masters in International Business Economics & Management. Daire has extensive root cause analysis and statistical analysis skills developed through both his professional and academic career. He currently acts as exploitation manager for the H2020 CYBELE project. Email: daire@evenflowconsulting.eu