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PROBLEMS AND SOLUTIONS FOR THE MANAGEMENT OF A UNITARY SYSTEM OF LANDSLIDE MONITORING NETWORKS: AN EXPERIENCE IN NORTH ITALY

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EXTENDED ABSTRACT

Le banche dati dei servizi geologici europei conteggiano circa 850.000 fenomeni franosi distribuiti su tutto il continente, di cui 620.000 sul territorio italiano. Con numeri così elevati è evidente come non sia possibile pensare di risolvere il problema del rischio da frana esclusivamente con interventi di tipo strutturale. In ragione di ciò negli ultimi decenni sono andate sempre più sviluppandosi misure non strutturali quali le reti di monitoraggio, a controllo dei fenomeni franosi, finalizzate a garantire la sicurezza dei cittadini. In quest'ottica il Centro di Monitoraggio Geologico (CMG) di ARPA Lombardia ha sviluppato e realizzato uno specifico progetto, denominato ARMOGEO, che garantisse, oltre allo sviluppo qualitativo e quantitativo delle preesistenti reti di monitoraggio, anche la gestione unitaria delle stesse. Alla base di tale scelta di unitarietà vi sono state molteplici valutazioni che miravano a: realizzare una struttura tecnica specializzata, facilitare la condivisione dei dati mediante formati unitari, predisporre un unico portale pubblico di gestione e consultazione dei dati, utilizzare programmi di acquisizione trasmissione dati che evitassero il *lock in* tecnologico, predisporre un unico magazzino ricambi che contribuisse a minimizzare i tempi di manutenzione delle reti. Lo studio, analizzando le varie fasi nelle quali può suddividersi lo sviluppo del progetto, esamina le problematiche ed i vantaggi che derivano dalla gestione unitaria di decine di reti di monitoraggio.

L'attività ha avuto avvio con una analisi a campo, con una raccolta e valutazione degli studi e della documentazione preesistente e mediante una analisi storica condotta con le tecniche dell'interferometria satellitare sulle aree oggetto di studio. Si è poi sviluppata la progettazione, dalla fase preliminare all'esecutiva, dove sono state definite le caratteristiche delle perforazioni, della strumentazione superficiale e profonda, nonché dei sistemi di alimentazione e trasmissione dei dati. Una volta terminata la realizzazione delle reti ed acquisiti una serie significativa di dati è stato possibile dare avvio a specifici studi di modellazione con definizione delle soglie d'allertamento, per tutte le aree con finalità di *early warning*. Al termine di queste attività, che hanno impegnato ARPA per 7 anni ed hanno avuto un costo di oltre 3 milioni di euro, il CMG controlla 44 reti di monitoraggio delle quali 28 con finalità di allertamento. I dati acquisiti dalla rete, costituita da 891 sensori con trasmissione *near real time*, risultano ogni anno mediamente 24.660.000 cui vanno sommati i circa 70.000 dati provenienti da misure e sensori ad acquisizione manuale. Le attività sulle reti hanno comportato come facilmente desumibile dalle tabelle riportate, costi di infrastrutturazione e messa in esercizio notevolmente differenti (da qualche decina di migliaia di euro a qualche centinaia di migliaia di euro) in relazione alle specificità dei singoli dissesti ed alla finalità, conoscitivo o di allertamento, del monitoraggio. Lo studio approfondisce anche le economie di scala che si sono determinate con la gestione unitaria di decine di reti di monitoraggio. Suddividendo le spese gestionali in quattro macro voci (costi del personale, costi di manutenzione, costi dei servizi specialistici ed altri costi) vengono illustrati i costi gestionali delle 44 reti evidenziando le economie ottenute; dal 19% al 40% per le reti più complesse e dal 39% al 58% per le reti conoscitive dove i costi fissi sono preponderanti. La discussione prende in esame anche il numero di tecnici necessari per una efficace gestione unitaria e quali debbano essere i percorsi di formazione ed organizzazione all'interno di una struttura pubblica per giungere a quella specializzazione, nella gestione delle reti, che è essenziale per poter garantire una ottimale e rapida gestione di situazioni complesse e mai completamente codificabili come sono quelle determinate dalla pericolosità da frana.

Fra le problematiche viene analizzata quella determinata dalla gestione di 25 milioni di dati/anno con particolare riferimento alle segnalazioni prodotte dagli algoritmi che implementano i valori di soglia definiti, come da linee guida, in tre livelli crescenti di pericolosità. Per quanto riguarda l'emissione dell'allerta di livello più elevato, non essendoci come ad esempio stabilito dalla normativa norvegese, una definizione di tempo minimo (72 h) prima della previsione di collasso si deve operare tenendo in considerazione sia il tempo necessario per la valutazione ed emissione dell'allerta che quello per la messa in atto delle azioni di protezione civile connesse allo scenario atteso.

Complessivamente è possibile concludere che l'esperienza descritta evidenzia come la gestione unitaria di decine di reti di monitoraggio con finalità di allertamento non solo sia possibile ma è certamente il metodo ideale per giungere ad una mitigazione del rischio da frana per il tramite del monitoraggio.

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ABSTRACT

International scientific studies show that landslides are widespread throughout Europe, especially in Italy (Herrera *et alii*, 2018; Trigila *et alii*, 2007). Due to the phenomenon high dimension, it's not possible to act in all the areas with structural operations to reduce the landslides risk. For this reason, the geological monitoring networks represent an efficacious and cost-effective system to protect the population. ARPA Lombardia, with Geological Monitoring Centre (CMG), has worked for the last years for the management of dozens of early warning geological monitoring networks. CMG has been monitoring a total of 44 landslide areas and has been collecting and analysing about 25 million data for the last years. These data are acquired by sensors every 10 or 30 minutes. This paper will take in consideration the essential and critical aspects linked to the planning, integration and unitary management of numerous monitoring networks to control landslides. The CMG's experience has shown how the unitary management of the warning systems of multiple monitoring networks is the ideal method to manage landslides problem and reduce hazard. This paper highlights how the technician's formation on landslides and geological monitoring networks has allowed better management of the landslide risk problem. Finally, it is quantitatively demonstrated that management costs show significant reductions after the implementation of this unitary management.

Keywords: *early warning system, landslides, landslide monitoring networks, unitary management of landslide monitoring networks*

INTRODUCTION

The European national geological services database registers 849. 543 landslides in Europe (Herrera *et alii*, 2018). The Italian territory is also affected by geohazard instability and landslides. ISPRA (National Institute for Environmental Protection in Italy), with the help of Regions and Autonomous Provinces, has published the catalog "Italian Landslide Inventory" (IFFI) where approximately 620.000 landslides are identified. The IFFI catalog has been realized using standardized and shared modality as: the census, the collection of historical data, territorial analysis with aerial photointerpretation and field survey (Trigila *et alii*, 2013; Trigila *et alii*, 2007).

The geohazards throughout the Italian territory have been identified thanks to the combination, carried out by ISPRA (Trigila *et alii,* 2018), of specific studies at basin level, called "Piani di Assetto Idrogeologico (Geohazard Asset Plans) – PAI".

This study highlights that 8,4% of the national territory (25.000 km^2) is threatened by high or very high landslide hazard. In these areas only minimal maintenance work on the pre-existing buildings is allowed. The comparison (in a GIS environment) between landslide hazard areas (PAI) and single areas where the national territory is divided shows the amount of people threatened by landslides. The result of this study pointed out that 2,2% of the Italian population (over 1,2 million citizens) is threatened by the landslides hazard (Trigila *et alii*, 2018).

4.862 landslides occurred worldwide from January 2004 to December 2006 and they caused 55.997 deaths (Froude *et alii*, 2018).

It is important to remember that the demand for safety against the natural hazards is higher and higher in the technologically developed part of the world. For this reason, in the last decades the public administrations have done important economic investments for structural (physical mitigation works) and not structural operations to mitigate the natural risks (Maciotta *et alii*, 2016; Mansour *et alii*, 2011).

The physical mitigation works (structural operations) to reduce the risk are the most numerous and known, mostly for the territorial visibility. Taking into consideration all the 620.000 landslides and in particular the phenomena that involve tens or hundreds of millions of cubic meters of material, it is not always technically and economically possible or convenient to intervene with physical mitigation works.

Structural operations, like for example citizen relocations, have great impact in social terms.

Law doesn't allow today the citizen relocations for landslide risk, such as those that occurred in past centuries, thanks to laws like n. 445 dated July 9th 1908, with king Vittorio Emanuele III di Savoia acting "by God's will". For this reason, landslide monitoring systems have been increasingly developed in last decades, the features of which have been defined both at European level (Bazin, 2012) and at Italian level (Dei Cas *et alii*, 2021b).

Landslides monitoring network is only one of multiple elements that constitute an EWS (Early Warning System) that, according to United Nations International Strategy for Disaster Reduction, can be defined as: "*the set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss*".

An EWS must have four interrelated elements: knowledge of the risks, monitoring and warning service, dissemination/communication of information and, at last, response capability.

According to the international scientific papers, a Landslide Early Warning System (LEWS) can be local or territorial (Calvello 2017; Krøgli *et alii*, 2018) (Figure 1).

The goal of a local LEWS is the study and the issue of warning about a single active or dormant phenomenon at local scale.

On the other way, the focus of a territorial LEWS is the issue of warning about the occurrence of multiple landslides at basin or regional scale.

It is obvious that the focus of local LEWS is to protect, through specific activities such as temporary evacuations, the population placed in the risk area. The goal of the territorial LEWS is to issue a "*generic warning*" when, inside a large area or in all the region, the landslide hazard begins to increase.

Typically, a territorial LEWS is based on meteorological forecasting and it has a geo-morphological approach (Intrieri *et alii*, 2019).

The LEWS can be also divided in alarm, warning or forecasting system (Stähli *et alii*, 2015; Pecoraro *et alii*, 2018).

The alarm systems are based on a predefined threshold and the danger signal (e.g., red flashing lights accompanied by sirens) is automatically activated without any human control because the time between the detection of the parameters of ongoing hazard events and the event itself, is too short (seconds or maximum minutes) (Walter *et alii*, 2019; Coviello *et alii*, 2019).

The focus of warning system is to detect significant changes, in the landslide behavior, based on predefined thresholds (e.g., displacements in terms of rate, velocity or acceleration). These precursory signals highlight specific landslide behavior before the mass collapsing.

The time lapse, which occurs between exceeded thresholds and the failure, must be higher or equal to the functional time that allows experts to analyze data value and the situation in order to implement the appropriate intervention measures (e.g., road closure or evacuation)

Forecasting systems are based on data interpretation conducted on a regular basis, usually daily, and identify landslide hazard on large areas. These systems are typical of a territorial LEWS.

On the subject of monitoring networks, typical of a local LEWS classified as warning, this paper illustrates ARPA's (Regional Agency for Environmental Protection) experiences in the ARMoGeo (Italian acronym for Development and Expansion of Geological Monitoring Networks) project. It'll show essential and critical steps about set up, maintenance and single management of several monitoring networks of early warning.

An important example of unitary landslide monitoring system in Europe is managed by the NVE (Norwegian Water Resources and Energy Directorate). They manage 24/7 monitoring and early warning systems of 7 high-risk landslides (Kristensen *et alii*, 2020).

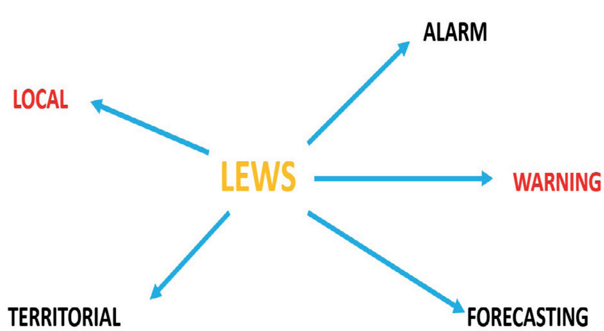

Fig. 1 - A LEWS can be classified in relation to the territorial extent of the phenomenon or the type of warning system. In red colour identifies LEWS managed from CMG

Even if ARPA's early warning networks is larger than the Norwegian one, it's not mentioned in the last and more interesting scientific papers about LEWS (Pecoraro *et alii*, 2018; Ingeborg & Krøgli *et alii,* 2018).

This paper will hopefully contribute to inform about this important project and fill these gaps.

Study area

This study will consider public authorities' activity in the field of landslides hazard mitigation in the Alps and pre-alps of Lombardy, in the Northern part of Italy.

After the Val Pola landslide in July 1987 (Govi M. *et alii*, 2002) Region Lombardy's public administration spent 16 million eur for the realization of a Geological Monitoring Centre (CMG) in accordance with national law 102/90.

Lombardy's ARPA's CMG is responsible for the design, installation and supervision of all the geological monitoring systems placed on those landslides that are considered, with an exclusively qualitative assessment, as the most dangerous of the region.

The population in Lombardy living in these high or very high landslide hazard areas is over 44.000 units (about 0,5% of the citizens of the whole region) (Trigila *et alii*, 2018; Salvati *et alii*, 2021). For this reason, Region Lombardy's public administration decided to increase the number of LEWS.

These numerous LEWS generate a great number of data values that should be unitarily managed in order to increase efficiency.

METHODOLOGY

The features of monitoring networks focused on early warning will be described in this section

As already mentioned, it is not possible to carry out structural works to protect against the danger of landslides everywhere, for this reason landslide monitoring networks represent a convenient way to reduce risks (Casagli *et alii*, 2021).

The essential features which must be concurrently present to consider a landslide monitoring network an early warning system, are (Dei Cas *et alii*, 2021b):

1. collection of data values must be in real time and their transmission must be in near real time, at least.
2. The equipment installed on the landslide, designed and studied to suit the specific slope failure, has one or more alarm thresholds. Data values collected must be analyzed using these studies as a base.
3. Landslide monitoring network must have a manager in charge of analyzing data values and of maintenance activity (both standard maintenance and repairs activities). The manager must promptly repair any instrumental or transmission malfunctions. If necessary, he analyzes the automatic activation thresholds to avoid too many false

alarms, not related to real movement, which could reduce attention towards an alert signal (Sättele *et alii*, 2015b).

In the lack of one of these three features, a geological monitoring network cannot work as an early warning one.

The redundancy principle must be taken into high consideration when designing an early warning monitoring network (Iso en 18674-1, 2014). The redundancy principle implies that two or more elements (e.g., sensors) with the same function need to be installed in a landslide monitoring network to guarantee its liability.

For this reason, the redundancy principle must be used to set up monitoring instruments.

Equipment of the same kind must be set up to avoid monitoring the landslide with only one device (Figure 2) and, at the same time, more piece of equipment of different kind must be set up in the same place to ensure monitoring the landslide displacement with different kind of device (Figure 3). The redundancy principle must be also applied on the power and transmission systems, on the databases and on the analysis software. The redundancy in LEWS' equipment, power supply systems, data download, storage, analysis and communications are recommended from "Guidelines for landslide monitoring and early warning system in Europe" and is specifically request by "Norwegian building codes" (Kristensen L. *et alii*, 2020).

Some studies claim that sturdiness should be preferred over accuracy for the landslide early warning network (Casagli *et alii*, 2021).

A continuous analysis of the data (see points 2 and 3 on the previous page) demands the repair of any faults as fast as possible.

This is possible only if the management plans a fast workers availability in order to repair any out of services undermining the acquisition and transmission of data values, in short time.

More serious is the fault for the possible issue of a warning notice, faster needs to be the availability to repair the defect.

The effectiveness of the monitoring network requires the proper planning of technician availability (on call technicians), since they are in charge of analyzing data values (Sättele *et alii*, 2015b; Dei Cas *et alii*, 2021b).

Acquired data values are automatically analyzed by calculation algorithms in the warning monitoring networks; this aims at numerically quantify the danger of the landslide area in that moment.

Data input for the calculation algorithms are the last (it depends on the nature of the equipment and thresholds) data values acquired

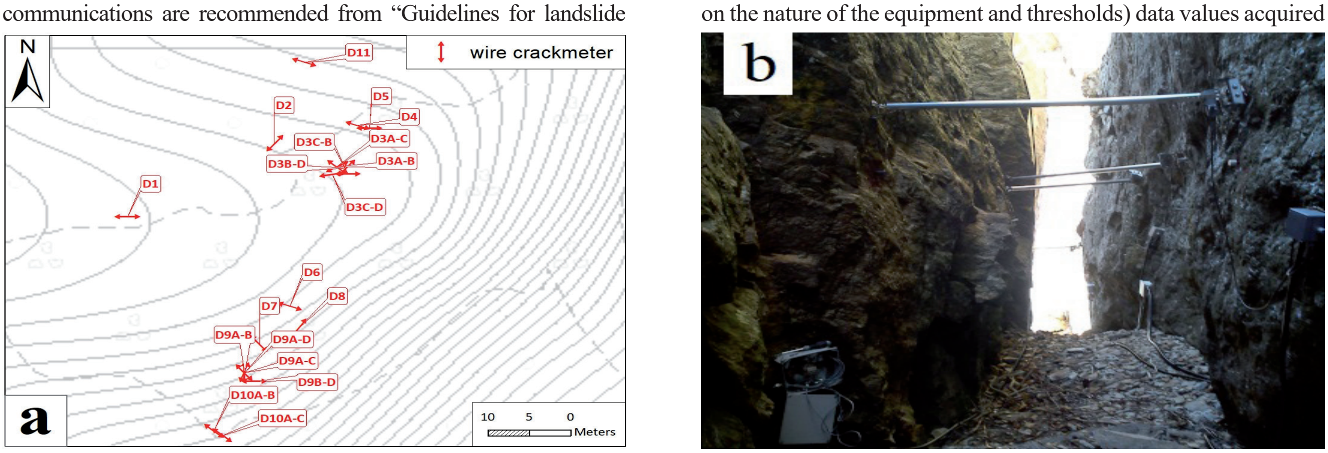

Fig. 2 – Rock fall, Il Pizzo (Branzi, BG): 2a monitoring network map; 2b more wire crackmeters used to control the same rock fracture. Archive photo CMG

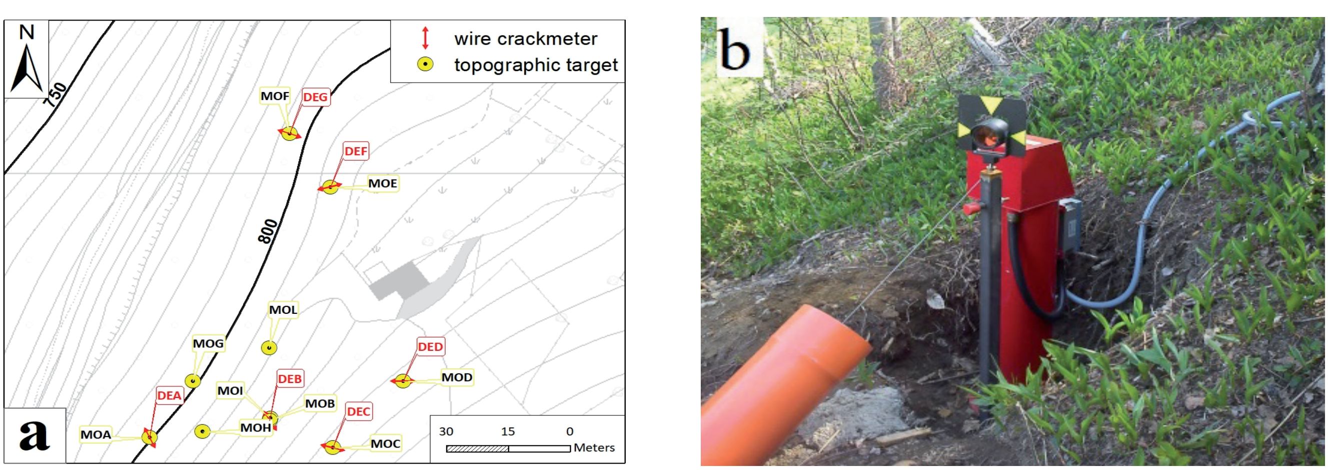

Fig. 3 – Debris translational slide, San Giorgio Talamona (SO): 3a monitoring network map; 3b wire crackmeter and topographic target. Archive photo CMG

with the devices on the slope failure. If the result of the algorithms is higher than the fixed threshold there will be a warning notice. It's necessary then to check this notice to avoid false alarm.

The examination of warning notice implies all the activities (e.g., electronic check to verify that the equipment had a good performance, inspection on field, verify with manual measurement that the devices properly work…) necessary to confirm the correctness and the meaningfulness of the warning notice.

These checks and manual measurements must take place within few hours after the alarm signal for early warning monitoring networks. This is possible only if a fast technician and workers availability plan has been scheduled.

The ARMOGEO project: times, and activity

Art. 6 of the law n. 5 of 31 July 2013 issued by Lombardy Region changed the institutive law of ARPA Lombardia. The Agency supports the Region technically and scientifically "*in prevention and controls activities to the authorities for the civil protection interventions in areas at environmental risk also through the progressive acquisition, where necessary through specific agreements, of the geological monitoring systems in Lombardy, managed by different authorities, guaranteeing their technological adaptation and enhancement, in order to develop a single integrated regional network*".

Law n. 5 created the prerequisite for unifying in a single entity the management of landslide risk monitoring networks, up to that moment managed by different authorities in different ways.

Before this law was issued in Lombardy, regional authority was used to give public fund to a municipality (or higher rank authority) to install and control a geological monitoring system; all the authorities did their best to make this work, but the results were not uniform.

ARPA's CMG only managed 17 landslides monitoring system until 2009 (10 early warning monitoring and 7 cognitive monitoring). The ARMOGEO project intended to complete the management switch of tens of landslides monitoring system, from municipalities to ARPA's CMG.

The choice of the Lombard legislator was dictated by both technical reasons (only one high specialized subject manages the process) and economic reasons (benefiting from economies of scale).

The priorities and aims (cognitive or early warning) of CMG's monitoring systems were chosen thanks to an exclusive qualitative assessment by Region Lombardy's administration.

Based on these indications, ARPA has implemented a work strategy that would allow to proceed simultaneously with the numerous activities. Figure 4 shows the essential steps to complete the integration project of the individual networks with the purpose of early warning.

Some basic choices were fundamental in order to develop the network integration project, they're summarized as follows:

1. an adequately structured and trained technical staff to be able to supervise the installation first and then the management of the geological monitoring networks.
2. Design with the same unitary logic the adaptation of the networks for the creation of an integrated structure on the territory with all regional monitoring systems, also to facilitate data sharing. To achieve this last purpose, it was necessary to define unique data transmission formats (identified in the FTP protocol) and data files (ASCII), according to a predefined structure by ARPA.
3. Have a single proprietary web portal available for the management/ storage of data, to which the different companies in charge of the management and maintenance of the instrumentation must conform, overturning the role according to which the user of the service adapts to the supplier's web interface of the service and not the other way around.
4. Establish that at the end of the installations the programming source files of the acquisition and transmission systems must be in free and editable format, including any libraries and all accompanying software, so that ARPA can freely dispose of them. An open system, in addition to complying with the Directive 2003/98/EC of the European Parliament of 17 November 2003 relating to the reuse of public sector information, allows in fact to maintain greater autonomy in the management of subsequent maintenance contracts, avoiding a technological lock-in linked to the use of proprietary formats.
5. Integrate the spare parts warehouse, to be restored after each material pick up, to reset the supply times for the instrumentation subject to maintenance/replacement.

It took 7 years to complete the project ARMOGEO. As shown in the time table (Figure 4), 61 macro-activities have been planned for the implementation of the project. Upon completion of the project, a single Lombard system for monitoring landslides was created, consisting of 28 geological early warning monitoring networks and 16 cognitive monitoring networks.

The first part of the project, which lasted over two and a half years, was dedicated to data collection, inspections and study of the numerous monitoring networks (67), reported by the Lombardy Region.

Subsequently, an analysis of the collected data was carried out by comparing them with those acquired, entrusting a specific assignment, from the satellite interferometric analysis in the years 2011-2014 (Antonelli *et alii*, 2019; Dei Cas 2017).

After that phase, 18 feasibility studies have been planned for 15 newly acquired networks and 3 networks already under ARPA management on which integrations were necessary.

For the 15 new areas, the purpose of monitoring was finally defined in cognitive or early warning.

The minimum features for transmission redundancy with the use of satellite media were then analyzed. The in-depth analysis identified as the minimum robustness characteristic required of

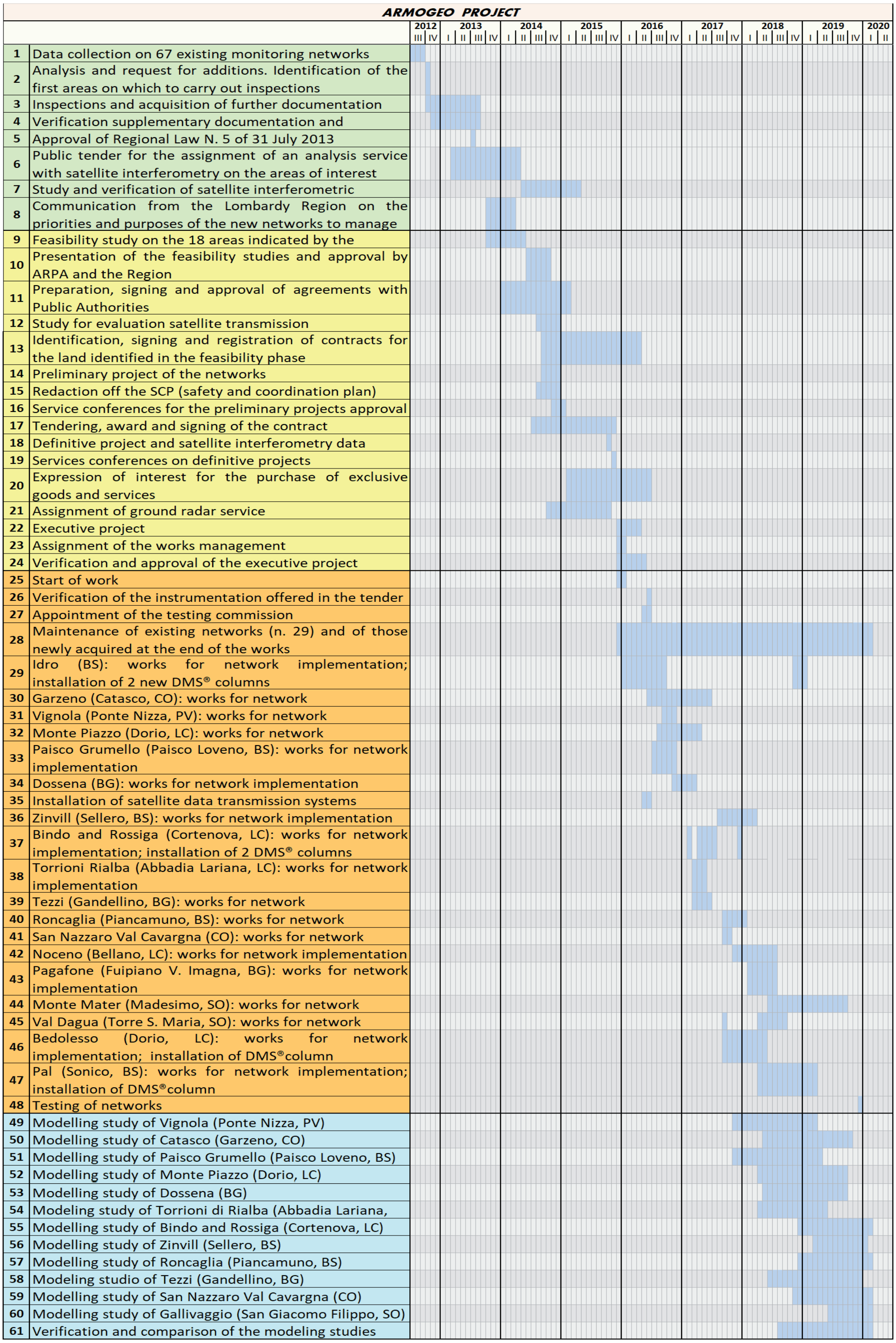

Fig. 4 - ARMOGEO project Gantt's diagram: the analysis (green), planning (yellow), adaptation/enhancement activities (orange) and geological modelling (cyan) steps

the operator, a readiness for continuous transmission of 99.7% of the total operating period.

With the stipulation and signing of agreements and deeds, the existing monitoring networks were acquired and the availability of areas and structures was requested.

After the development of the preliminary project, service conferences (meeting between public administrations to authorize the work) were convened with the competent authorities in environmental, landscape and urban-building matters for any prescriptions.

After the assignment of safety tasks and the drafting of the specifications, authorities put out an invitation to tender.

The start of the contract and the executive design therefore took place about three and a half years after the start of the activities.

The activities in the following 3 and a half years were as follows:

- approval of executive projects;
- execution of the adaptation interventions;
- testing of networks;
- modelling study on 12 slope failures, with identification of warning thresholds.

RESULTS

The average time for the construction/implementation of a network was seven months (Table 1). It took about two months for simpler networks or networks without surveys.

Modeling studies for new networks took longer execution times due to the need to acquire at least one year data. The studies allowed the development of a kinematic model, with the proposal and verification of early warning thresholds

The settings of warning thresholds for the single landslide are essential for a LEWS because it is necessary to define numerical values which prevent the false alarms and, more important, missed alarms (Bazin, 2012).

Some of the numerical values of the thresholds of this project can be seen in Table 2.

An average time of 15 months was required for the execution and approval of the studies.

The cost of the entire ARMOGEO project (design, execution of works, modelling study on 12 areas) is over 3 million euros (3.172.200,00 €) as detailed in Tab 1.

In addition to this amount, the costs (about 100,000 euros) incurred in the preliminary phase must also be considered (satellite interferometric analysis of the cosmos sky med constellation, study to identify the minimum characteristics for the back-up transmission with satellite), and the other costs for the execution of the interventions (assignments of Works Management and Safety Coordination according to Law n. 81/08).

At the end of the ARMOGEO project settlement, the geological monitoring system of ARPA Lombardia consists of 44 networks (Figure 5), 33 of which with real-time data transmission, composed of both automatic equipment with

LANDSLIDE	monitoring networks costs	geological modelling studies costs	Total cost	instruments	work start date	months of work	Geological modelling study start data	months
TORRIONI DI RIALBA	€ 48 600.00	€ 27 500.00	€ 76 100.00	1RTU; 8Cm; 8IpS; 9Tm; 1RG; 2WL	17/02/2017	2	05/04/2018	15
MONTE PIAZZO	€ 238 600.00	€ 27 500.00	€ 266 100.00	2Bh (320 m); 5 GPS	08/09/2016	7	05/04/2018	17
VIGNOLA	€ 38 200.00	€ 27 500.00	€ 65 700.00	1RTU; 3Cm; 1Th; 1RG; 1W	05/09/2016	3	24/11/2017	17
DOSSENA	€ 113 700.00	€ 27 500.00	€ 141 200.00	4RTU; 6Bh (350 m); 18IpD; 6Cm; 3Pz; 1RG; 1Tm	28/11/2016	4	21/06/2018	15
CATASCO	€ 180 000.00	€ 27 500.00	€ 207 500.00	2RTU; 4Bh (410 m); 8IpD; 1Pz; 1TS; 1W	20/06/2016	11	21/06/2018	18
RONCAGLIA	€ 59 400.00	€ 27 500.00	€ 86 900.00	3RTU; 12 IpD; 3Pz; 1RG, 1Th; 1 Sg	05/09/2017	4	01/02/2019	12
TEZZI GANDELLINO	€ 96 800.00	€ 27 500.00	€ 124 300.00	1RTU; 4Bh (265 m); 16IpD; 2Pz; 1RG; 1Tm	23/03/2017	4	21/06/2018	18
PAISCO E GRUMELLO	€ 87 000.00	€ 27 500.00	€ 114 500.00	3RTU; 2Bh (180 m); 16 IpD; 1Pz; 1RG; 1Tm	25/07/2016	15	24/11/2017	17
SAN NAZZARO	€ 88 300.00	€ 27 500.00	€ 115 800.00	5RTU; 1Bh (100 m); 8Cm; 1Pz; 4IpD; 1IpS; 1RG; 1Tm	01/08/2017	3	21/12/2018	13
ZINVILL	€ 101 900.00	€ 27 500.00	€ 129 400.00	2 RTU; 6Bh (290 m); 12IpD; 3Pz; 1RG; 1Tm	24/08/2017	6	01/02/2019	12
BINDO ROSSIGA	€ 256 400.00	€ 27 500.00	€ 283 900.00	2Bh (130 m); 1Ts; 2 DMS (24 m); 1W; 2Pz	21/02/2017	10	21/12/2018	13
BEDOLESSO	€ 233 400.00		€ 233 400.00	1RTU; 5Pz; 3 GPS; 2Bh (240 m); 1 DMS (60 m)	26/09/2017	7		
VAL DAGUA	€ 108 600.00		€ 108 600.00	1RTU; 5Bh (250 m); 4IpD; 1Pz; 1RG; 1Tm	17/04/2018	5		
PAGAFONE	€ 186 400.00		€ 186 400.00	1RTU; 2Bh(245 m); 8IpD; 3Pz; 1RG; 1Th; 1Bm; 1WG; 1Hm; 5 GPS	01/02/2018	6		
NOCENO	€ 108 900.00		€ 108 900.00	2 Bh (200 m); 4 GPS	23/11/2017	7		
PAL	€ 287 400.00		€ 287 400.00	3 Bh (350 m); 4IpD; 1DMS (100 m)	26/04/2018	11		
MATER	€ 247 900.00		€ 247 900.00	3 Bh (320 m)	28/06/2018	15		
IDRO	€ 360 700.00		€ 360 700.00	1RTU; 3 Bh (210 m); 10 IpD; 1RG; 7 GPS; 1 DMS (27 m)	18/01/2016	5		
GALLIVAGGIO		€ 27 500.00					27/05/2019	9

RTU (Remote Transmition Unit; Cm (Crackmeter); IpS (superficial Inclinometric probe); IpD (deep Inclinometric probe); Bh (Borehole); GPS (GPS Station); W(Webcam); Pz (Piezometer); WL (Water Level); TS (Topographic Station); DMS(R) (Differential Monitoring of Stability); Tm (Thermometer); RG (Rain Gauge); SG (Snow Gauge); Bm (Barometer); WG (Wind Gauge); Hm (Hygrometer)

Tab. 1 - ARMoGeo project. Costs and lead times. In the column 2 the monitoring networks costs, in the column 3 geological modelling studies costs (the total cost for the 12 modelling is equal to 330000, it has been divided equally by each landslide), in the column 5 instruments and boreholes. In the last four columns the date of work start and the time of work, geological modelling study for the single network.

Landslide	type	Threshold	1 level (attention)	2 level (moderate)	3 level (elevate)
Vignola	rockfall	Crackmeters velocity	1 (mm/day)	2 (mm/day)	5 (mm/day)
Paisco e Grumello	rotational landslide	inclinometer velocity	10 (mm/30 day)	10 (mm/10 day)	20 (mm/10 day)
Monte Piazzo	rotational landslide	average GPS velocity	1 (mm/h)	2 (mm/h)	5 (mm/h)
Torrioni di Rialba	rockfall	Crackmeters velocity	1 (mm/day)	2 (mm/day)	5 (mm/day)
Dossena	rotational landslide	inclinometer velocity	5 (mm/30 day)	15 (mm/10 day)	25 (mm/10 day)
Catasco	rotational landslide	average topographic velocity	2 (mm/h)	4 (mm/h)	6 (mm/h)
Tezzi	rotational landslide	average inclinometer velocity	1.2 (mm/h)	2.4 (mm/h)	3.6 (mm/h)
San Nazzaro	rotational landslide	average inclinometer velocity	0.3 (mm/h)	0.7 (mm/h)	1.0 (mm/h)
Bindo	rotational landslide	average topographic velocity	2 (mm/h)	4 (mm/h)	8 (mm/h)
Roncaglia	rotational landslide	average inclinometer velocity	0.3 (mm/h)	0.5 (mm/h)	0.8 (mm/h)
Zinvill	rotational landslide	average inclinometer velocity	0.8 (mm/h)	1.5 (mm/h)	2.4 (mm/h)
Gallivaggio	rockfall	radar velocity	2 (mm/day)	3 (mm/day)	4 (mm/day)

Tab. 2 - Examples of thresholds for each ARMOGEO's landslide; for the meaning and effects of threshold levels read par. 4

near real-time data transmission (strain gauges, crack gauges, tiltmeter, load cells, inclinometer probes, pressure transducers, chains multiparametric, topographic total stations, GPS/GNSS antennas, ground radar, thermometers, rain gauges, hydrometers, hygrometers, snow gauges, barometers, anemometers, web cams for a total of 891 sensors) and stations for the execution of manual measurements (inclinometer and piezometric tubes, deep strain gauges, TDR cables, distometric, topographic and GPS points, bar strain gauges) (Table 3).

In total, the automated networks (Table 4) acquire an average of 24,660,000 data values per year, and approximately 70,000 data values from manual surveys (Table 5).

Once we described timing, costs and how ARPA Lombardy acquired and technically aligned the 28 monitoring networks with alerting purpose, it is now essential to show how these networks have been managed. The first step was the creation of some

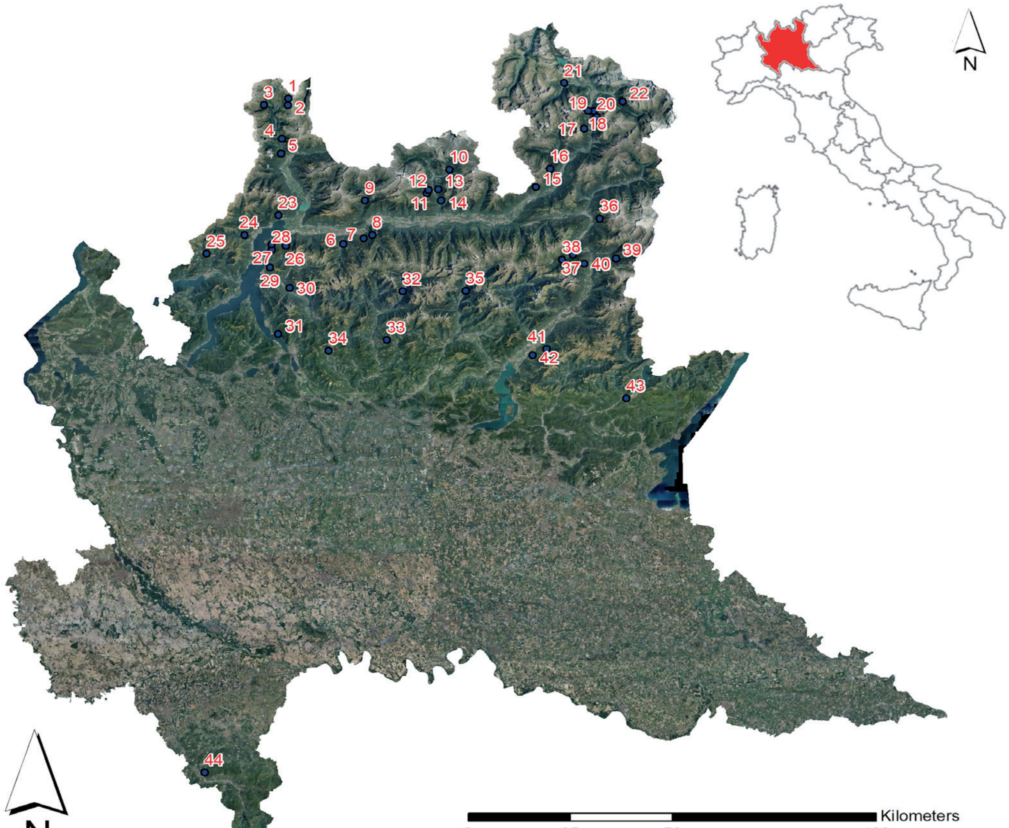

Fig. 5 - Location of the 44 geological monitoring networks

Code	Landslide Name	Instruments			Data	Purpose	threshold type
		automatic	manual	weather inst.	Acquisition		
1	CRESTA EMET		GPS S; GBR;		M	C	
2	M. MATER		DIT; GPS S; GBR;		M	C	
3	VAL FEBBRARO		TEm; GPS S; Tg S;		M	C	
4	GALLIVAGGIO	GBR;	TEm;		Rt/M	EW	surface movement velocity
5	VAL GENASCA	WCm; DMS ®; Pz; TS;	TEm; DIT; Pz; GPS S;	RG; Tm; SG;	Rt/M	EW	surface movement velocity
6	BEMA		DCm; DIT; Pz;		M	C	
7	SAN GIORGIO		TEm; Tg S;		M	C	
8	LA PRUNA		GPS S;		M	C	
9	SCAIUN		GBR;		Rt/M	EW	surface movement velocity
10	CAMPO FRANSCIA	WCm;	DCm; TEm;	RG; Tm; SG;	Rt/M	EW	surface movement velocity
11	MASONI	WCm; IpD;	DIT; Pz; GPS S;	RG; Tm; SG;	Rt/M	EW	surface movement velocity; deep movement velocity
12	TORREGGIO A	WCm;	DIT;		Rt/M	EW	rainfall; surface movement velocity;
13	DAGUA	DMS ®; Pz;	DIT; Pz; GPS S;	RG; Tm;	Rt/M	C	
14	SPRIANA	WCm; IpD; Pz;	TEm; DIT; Pz;	RG; Hm	Rt/M	EW	surface movement velocity; deep movement velocity
15	M. MASSUCCIO		GPS S;		M	C	
16	ARLATE		GPS S;		M	C	
17	VAL POLA	WCm;	TEm; DIT; GPS S;	RG; Tm; SG;	Rt/M	EW	surface movement velocity
18	SUENA		WCm; DCm; TEm;	Hm	M	C	
19	BOERO		TEm;		M	C	
20	OULTOIR		TEm; GPS S;		M	C	
21	SEMOGO	IpD; Pz;	DIT; Pz;	RG; Tm;	Rt/M	EW	piezometeric raising
22	RUINON	WCm; GBR;	TEm; Pz; Tg S;	RG; Tm; SG;	Rt/M	EW	surface movement velocity
23	GERA LARIO	WCm;	TEm;	RG; Tm;	Rt/M	EW	rainfall; surface movement velocity;
24	CATASCO	IpD; Pz; TS;	DIT; GBR;	RG; Tm;	Rt/M	EW	surface movement velocity; deep movement velocity
25	SAN NAZZARO	Cm; IpD; Pz;	DIT; Tg S;	RG; Tm;	Rt/M	EW	deep movement velocity
26	BEDOLESSO	DMS ®; Pz; GPS A;	DIT; Tg S;	RG; Tm;	Rt/M	C	
27	MONTE PIAZZO	GPS A;	DIT; GPS S;		Rt/M	EW	surface movement velocity
28	MONTE LETEÈ	WCm;	DCm; Cm; TEm; DIT; Pz;	RG; Tm;	Rt/M	EW	surface movement velocity
29	NOCENO	GPS A;	DIT; Pz; GPS S;		Rt/M	C	
30	BINDO-ROSSIGA	DMS ®; TS;	Pz;	RG; Tm;	Rt/M	EW	surface movement velocity; deep movement velocity
31	TORRIONI DI RIALBA	WCm; Tm;	TEm; Tg S;	RG; Tm; Hm	Rt/M	EW	surface movement velocity
32	IL PIZZO	WCm; Tm;	TEm;	RG; Tm;	Rt/M	EW	surface movement
33	DOSSENA	Cm; IpD; Tm; Pz;	DIT; Pz; GBR;	RG; Tm;	Rt/M	EW	deep movement velocity
34	PAGAFONE	IpD; GPS A;	DIT; Tg S;	RG; Tm;	Rt/M	C	
35	TEZZI	IpD; Pz;	DIT; Pz; Tg S;	RG; Tm;	Rt/M	EW	deep movement velocity
36	PAL	WCm; DMS ®;	TEm; DIT;	RG; Tm;	Rt/M	EW	surface movement velocity
37	PAISCO	IpD; Pz;	DIT; Pz;		Rt/M	EW	rainfall; deep movement velocity
38	GRUMELLO	IpD; Pz;	DIT; Pz;	RG; Tm;	Rt/M	EW	rainfall; piezometric raising; deep movement velocity
39	VALLE	Cm; IpD; Tm; DMS ®;	DIT; Tg S;	RG; Tm;	Rt/M	EW	deep movement velocity
40	ZINVILL	IpD; Pz;	DIT; Pz; GPS S;	RG; Tm;	Rt/M	EW	deep movement velocity
41	VAL VEDETTA	IpD; Pz;	DIT;	RG; Tm;	M	C	
42	RONCAGLIA	IpD; Pz;	DIT; Pz;	RG; Tm; SG;	Rt/M	EW	deep movement velocity
43	IDRO	IpD; DMS ®; Pz; GPS A;	DIT; Pz; Tg S;	RG; Tm;	Rt/M	EW	surface movement velocity; deep movement velocity
44	VIGNOLA	Cm; GBR;	TEm;	RG; Tm;	Rt/M	EW	surface movement velocity

Tab. 3 - Other information about each monitoring system (Instruments abbreviation: WCm: Wire Crackmeters; DCm: Deep Crackemeter; Cm: Crackmeter; IpD: Deep Inclinometer; Tm: Tiltmeter; DMS ®; GPS A: GPS Station; TS: Topographic Station; GBR: Ground Based Radar; TEm: Tape Extensometer; DIT: Deep Inclinometric Test; Pz: Piezometer; GPS S: GPS Survey; Tg S: Topographic Survey; RG: Rain Gauge; Tm: Thermometer; SG: Snow Gauge;) – (Data Acquisition abbreviation: M: manual; Rt: Real time) –(Purpose abbreviation: C: Cognitive; EW: Early Warning)

Near real time transmission and acquisition sensors																					
RAIN GAUGE	THERMOMETER	HYDROMETER	SNOW GAUGE	BAROMETER	HYGROMETER	WIND GAUGES	ALBEDO GAUGE	GLOBAL RADIOMETER	NET RADIOMETER	STRAIN GAUGE	INCLINOMETRIC PROBE	TILTMETER	MULTIPARAMETRIC SENSORS (DMS SYSTEM)	PIEZOMETRIC	LOAD CELL	CRACKMETERS	GPS STATION	GPS MASTER	TOPOGRAPHIC STATION	GROUND SAR RADAR	WEB CAM
45	52	13	18	4	7	5	1	1	1	101	126	36	375	50	1	22	21	5	3	4	5

Tab. 4 - 891 different sensors (+5 webcam) which continually collect and transmit data values

Sensors and places for manual measurements									
DISTOMETRIC measurements	CRACKMETERS iron bar	CRACKMETERS	Multi-Point Borehole EXTENSOMETER	INCLINOMETER casing	PIEZOMETRIC casing	TOPOGRAPHIC master	TOPOGRAPHIC reflector points	GPS POINTS	TDR CABLE
275	2	9	11	67	76	22	139	79	25

Tab. 5 - In the places for manual measurements highlighted CMG collect about 70.000 data values every year

backups, not only in the designing phase of the monitoring system (number and typology of instruments, electric power systems, communicating systems), but also in data storage and analysis.

In this regard, the servers dedicated to data acquisition have been submitted to disaster recovery and business continuity policy (Figure 6) following the European guidelines for landslides monitoring (BAZIN, 2012). Data processing software, that compares data with previously fixed thresholds, produces a status file; this file is continually supervised to prevent software delay or interruption.

When an instrument measures a displacement greater than a defined threshold, the software sends an alert message. The message is sent with a different transmission method (SMS – Short Message Service and e-mail), to the CMG operations room where each piece of hardware is connected to an uninterruptible power supply and, at the same time, to two technicians on call (Figure 6).

The condition to manage every information produced by the

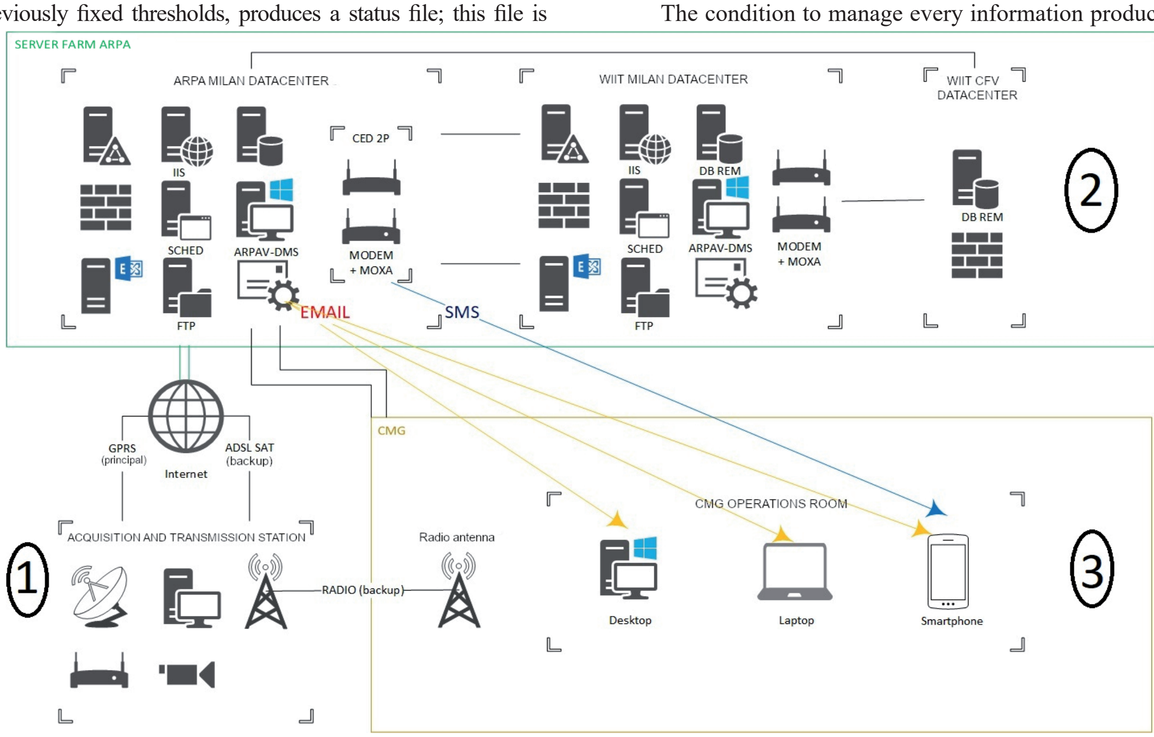

Fig. 6 - In the places for manual measurements highlighted CMG collect about 70.000 data values every year

many geological monitoring systems, on a unique web-portal, is the creation of that instrumental data (and related information) in respect of defined and unambiguous proceedings. According to the technical specifications of ARMOGEO all the data transmitted to ARPA servers must have the same naming convention.

CMG's work organization establishes that every day, including not working days, a technician (shift worker), an expert in landslide monitoring networks, oversees and verify, by accessing the web portal, the perfect functioning of the measurement sensors and hardware /software dedicated to data acquisition and analysis.

In detail, with the CMG's web-portal it is possible to make graphics of every sensor installed on landslide (Figure 7), locate them on the cartography, check information about thresholds, maintenance and sensors features, analyze their historical evolution, verify the correct operativity of powering and transmission systems, look the external appearance of the landslide thanks to the webcams installed in the areas.

The expert technician activates the necessary maintenance operations in the event of a malfunction. In this regard, ARPA has signed some maintenance contracts, with defined intervention times, ranging from a few days to a few hours, depending both on how much the malfunction is blocking the alert process and on how high the level of criticality is for the landslide.

If, on the other hand, the automatic systems detect that the threshold has been exceeded (2857 automatic alerts were counted in the two-years period 2019-2020) the first action of the expert technician (shift worker or on-call worker) is check and rule out malfunctions or instrumental damage; this operation is carried out by the technician based on a schedule, on which CMG personnel have been previously trained. If this operation doesn't exclude the possibility that the exceeding of the threshold was connected to a real landslide movement, the task of CMG personnel is to reach the site to carry out some manual measurements (additional to the data in real time), with the objective of confirming the movement of the landslide and therefore signaling one of the criticality levels identified on a specific modeling study.

In accordance with the guidelines for landslide monitoring and early warning systems in Europe, ARPA Lombardia established, on its early warning system, three alert levels which, as endorsed by some authors (Intrieri *et alii*, 2019; Loew *et alii*, 2016), are linked to the displacement, velocity or acceleration parameters of one or more sensors.

In Norway the highest level of warning, for the safe evacuation of inhabitants before the collapse must be issued with a warning time of not less than 72 hours (Kristensen *et alii*, 2020).

In Italy, however, there are no rules that define the warning

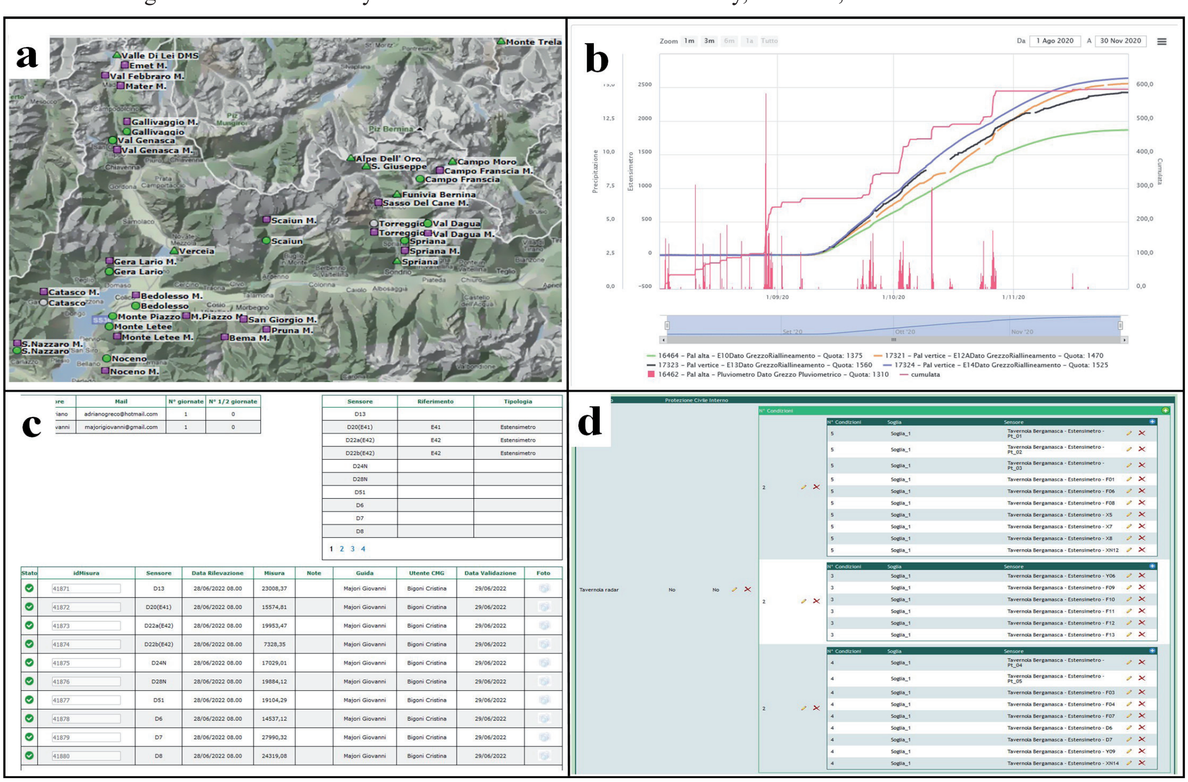

Fig. 7 - Example screenshots of web-portal: A: overview map of transmission or alerting status for each landslide (green dots for real time network, purple dots for manual network); B: example diagram showing rainfall and crackmeters data; C: mask for inserting data from manual survey; D mask for programming threshold data. Web-portal is available only for insiders

time before the collapse.

As stated in the "Guidelines for landslide monitoring and early warning systems in Europe", the actions corresponding to the 3 alert levels are, on an increasing scale:

1. activity only on the monitoring network;
2. increased monitoring and preparation for the alarm;
3. specific countermeasures to protect the population such as evacuations, road closures, etc…

For this reason, the lower warning level (named Attention) has the purpose to alert only the CMG technical staff on every change of the situation on the slope, which has to be analyzed.

The numerical threshold values are determined by the analysis of multi-year data values. The lower threshold (Attention) is generally above the seasonal oscillation.

The medium and higher alert levels (called Moderate and High criticality levels), have the purpose of drawing attention to the changing dynamics of the landslide also to all the institutions involved in the Civil Protection activities. In particular, the high alert level should show the behavior of the landslide at a time ΔT before the collapse; where ΔT is the maximum time interval defined as the sum of a T1 time, necessary to evaluate and communicate the situation, and a T2 time, necessary to carry out the interventions scheduled by the landslide emergency plan.

The threshold value of the upper level clearly depends on the associated scenario; a scenario where several houses or a hospital need to be evacuated will take several hours, so the T2 time will be much longer than a scenario where only the traffic needs to be interrupted.

For this reason, in a scenario with a long time T2 (for example when a hospital must be evacuated) the threshold must be conservative, and, therefore, more false alarm could be issued.

The guidelines suggest a proficient combination of expert judgement and forecasting methods.

In Lombardy this suggestion could be applicated on the landslide of Tavernola Bergamasca (monitoring network managed by CMG from 2021 after the end of ARMOGEO project) where thousands of people are involved in the emergency plan.

In relation to time T1, all necessary assessments as well as the sending of the alert message to the institutions must be completed in the shortest time possible and, at least, within 24 hours after receiving the alert message produced by the automatic evaluation system. However, the promptness in sending the alert message must not be detrimental to the reliability of the alert communication.

Management cost of early warning networks

The maintenance costs of all networks (33 networks with data in continuous transmission, in addition to 11 with exclusively manual measures), while benefiting from evident economies of scale, still represent a significant element.

With reference to 2020, the cost elements can be divided into 4 expense groups:

1. costs of the technical and administrative personnel necessary for the functioning of the CMG, excluding the expenses of the organizational units with functions transversal to many ARPA structures (e.g., personnel office, contract offices etc.);
2. costs for movement measurements and specialist services. This item includes ground and satellite interferometric measurements, the cost of the Alpine Guides for measurements on walls and exposed places, the cost of modelling, helicopter transport services;
3. costs for network and instrument maintenance services. The item includes the costs of active contracts, and the annual estimate, equal to 10% of the total value of the networks, to be allocated for the renewal and integration of the instrumentation making up the networks themselves;
4. other expenses: transmission costs, fees and electrical connections, land rents, headquarters and car costs, software and hardware costs, PPE (personal protective equipment), minor expenses, manual instrumentation.

Overall, the cost of these four groups can be estimated at around 2.5 M € as shown in Figure 8, even with the percentage breakdowns.

These costs have been divided between all the 44 monitoring systems, according to the instruments installed, the survey activities and the fixed costs: as shown in Tab. 6, management costs vary for each network system, starting from about 20 K€ for a cognitive network (e.g., San Giorgio) to around 140 K€ for an EW (e.g., Ruinon).

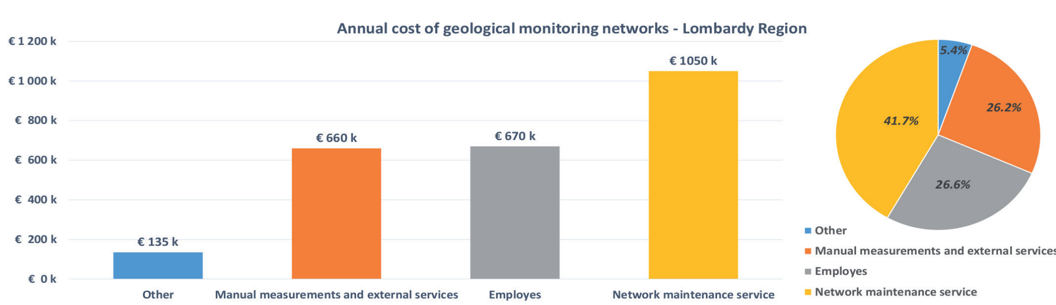

Fig. 8 - Annual maintenance costs by category of the geological monitoring networks

ID	NAME	COSTS	REDUCTION	ID	NAME	COSTS	REDUCTION
1	CRESTA EMET	30 400 €	50.9%	23	MADONNINA MACIALLI	43 700 €	41.9%
2	M. MATER	49 000 €	39.1%	24	CATASCO	73 000 €	30.2%
3	VAL FEBBRARO	22 700 €	58.2%	25	BURENA E BUBEGNO	57 800 €	35.3%
4	GALLIVAGGIO	84 300 €	27.2%	26	BEDOLESSO	65 000 €	29.5%
5	VAL GENASCA	89 200 €	26.8%	27	MONTE PIAZZO	62 200 €	33.7%
6	BEMA	26 700 €	54.2%	28	MONTE LETEÈ	47 000 €	40.2%
7	SAN GIORGIO	22 200 €	58.7%	29	NOCENO	48 300 €	39.5%
8	LA PRUNA	22 600 €	58.3%	30	BINDO-ROSSIGA	82 700 €	27.6%
9	SCAIUN	73 400 €	30.0%	31	TORRIONI DI RIALBA	53 700 €	37.0%
10	CAMPO FRANSCIA	42 700 €	42.5%	32	IL PIZZO	45 300 €	41.0%
11	MASONI	55 500 €	36.2%	33	DOSSENA	80 700 €	28.1%
12	TORREGGIO A	42 800 €	42.4%	34	PAGAFONE	71 000 €	30.7%
13	DAGUA	67 500 €	31.9%	35	TEZZI	60 300 €	34.3%
14	SPRIANA	55 800 €	36.1%	36	PAL	104 900 €	23.1%
15	M. MASSUCCIO	22 500 €	58.4%	37	PAISCO	47 300 €	40.0%
16	ARLATE	22 500 €	58.4%	38	GRUMELLO	39 700 €	44.3%
17	VAL POLA	60 600 €	34.2%	39	VALLE	111 900 €	22.0%
18	SUENA	23 400 €	58.9%	40	ZINVILL	52 300 €	37.6%
19	BOERO	23 400 €	58.9%	41	VAL VEDETTA	31 000 €	50.4%
20	OULTOIR	24 600 €	57.7%	42	RONCAGLIA	62 200 €	33.6%
21	SEMOGO	55 200 €	36.4%	43	IDRO	101 100 €	23.8%
22	RUINON	138 300 €	18.6%	44	VIGNOLA	97 200 €	24.5%

Tab. 6 - Management costs for each monitoring system (with reference to 2020); in column "reduction" are expressed economic benefits, in percent, from managing 44 monitoring system instead of 17

DISCUSSION

The unitary management of multiple landslide monitoring systems showed its positive effects in the spring of 2018, when there was first the acceleration and then the collapse of 6700 cubic meters of the Gallivaggio landslide (Menegoni *et alii*, 2020). These positive effects mainly concerned landslide risk management.

During Gallivaggio's landslide's acceleration the unitary management allowed the population evacuation, the closure of the church, the restaurant and the National Road (NR) 36 some days before the collapse (29 May 2019) (Dei Cas *et alii*, 2018; Carlà *et alii*, 2019; Dei Cas *et alii*, 2021a).

Five days passed between the issue of the warning level and the collapse. This notice complies with the Norwegian code's rule for the warning time, which states it shouldn't be less than 72 hours (Kristensen *et alii*, 2020).

Unitary management also has undeniable advantages from an economic point of view: by analyzing data on management costs in recent years, it was possible to evaluate that the management of 44 monitoring systems (as in 2020) instead of 17 monitoring systems (as in 2009) can define important economic benefits. Tab 6 shows the amount of savings for each type of monitoring system: savings start from 18% up to 40% for very complex monitoring system; for cognitive networks the savings are greater, ranging between 39% and 58%, since, for this type of network, fixed costs are the main ones.

The inclusion of several landslide monitoring networks in a single management system has clear and indisputable advantages (ranging from economies of scale to personnel qualification, through more effective information sharing and data archiving…), but we must take into consideration the important subject of the complexity in the management, for early warning purposes, of a landslide monitoring network system.

We'll discuss below some issues that may be of some relevance, especially for public administration office operating any early warning monitoring system (Pecoraro et alii, 2018).

In the first place it is essential to have a technical staff with specific training in the field of landslides and geological monitoring network; the number of employees must be enough to ensure office and guard activities in consideration of the exceeding of the threshold values for more than one landslide at the same time. This requirement highlights the difficulties of selecting, hiring and therefore motivating and remunerating employees, especially in the Italian public sector (Cassese, 2007; Merloni, 2006).

The technical staff, in addition to being an adequate number compared to the many geological monitoring networks, must have a cultural background (degree in technical science) and a physical prowess which allow them to carry out assessments on steep and remote areas (ex. reaching slope in adverse weather condition).

Each technician, once included in the technical staff, must undergo training periods to learn about the functioning of the various tools and software, the morphology and geology of the landslide areas (thanks to site inspections) and the position of the sensors and measuring points in the field.

Technicians must be properly trained and well equipped to operate safely on landslides. It is therefore important to periodically update the procedure which considers all the risks (reaching the area, moving to the monitoring points and carrying out the measures). This procedure must also contain any measures to improve safety, including periodic training of the operator. The educational aspect must include some briefing all along the year for the discussion and information acquisition about the evolution of the various landslides and ongoing activities in each monitoring network (Krøgli *et alii*, 2018).

Management of more alert monitoring networks implies the schedule of shifts with at least two technicians available even after office hours (from 5:00 p.m. to 8:00 a.m.). For these shifts the technical staff must be consist in, at least, 12 units.

The staff must operate remotely with rapidity; it is necessary to provide it with every useful device (portable pc, modem wi-fi, smartphone, software for remote connection) to be alerted and to enter the web-portal to verify the automatic alert messages.

After the analysis of the organizational needs to structure an adequate technical staff, it is now important to consider the problem of the big amount of data coming from many early warning monitoring networks.

It is easy to understand that when collecting 25 million data every year (on average, one data per second) the first problem is to train the technicians to pay attention only to the relevant ones. Precondition, for the solution of this problem, is to have the same acquisition and storage modality of data (ARMOGEO project) without which would be impossible to manage this amount of data.

The first data checking is carried out by comparing the latest data, transmitted by the sensors considered as more representative of landslide dynamics, to the oldest ones or with preset values. With this automatic operation it is possible to obtain a list of sensors or data stations that could be object of maintenance, but also, and more important, it is possible to have evidence of changing in slope dynamics that could bring to landslide collapse.

The attention of technicians will be focused on this reduced number of data/messages only (about the CMG geological monitoring networks from one to two thousand per year). If the monitoring network is well projected and built, the number of this messages will be:

1. directly proportional to number of sensors provided with thresholds;
2. function of the threshold value and processing algorithm.

With reference to the number of sensors or measurement points on which a threshold value will be applied, it has already been said that it depends on the significance, for forecasting purposes, of the acquired data.

Therefore, if we exclude some useful sensors in support of the data analysis (e.g., barometric data, air temperature data, etc.), it is clear that most of the sensors will be associated with threshold values. As far as ARMOGEO project is concerned, the number of sensors with threshold was 590 at the end of 2020.

Threshold values are defined in specific modelling studies that are particularly complex but strategic for the good functioning of EWS. An excessive number of threshold crossings might suggest reviewing and updating these modelling studies.

A monitoring network can also give some additional information about the landslide; on this point, it is very important that modelling studies (and relative thresholds) are periodically updated or confirmed in relation to this new knowledge. These updates are also done by entities similar to the ARPA's CMG like the NVE (Norwegian Water Resources and Energy Directorate). The NVE has recently updated its thresholds for the management of Veslemannen's landslide monitoring network (Kristensen *et alii*, 2020).

In the end, in reason of an eventual excessive number of alerts out of thresholds, changes in processing algorithm can be conducted to increase alert message reliability. It must be considered that an excessive number of false alarm (Probability of False Alarm PFA) would reduce confidence in the early warning system (Sättele *et alii*, 2015a).

The experience in Lombardy has shown that it is necessary to scientifically improve the landslide risk classification system.

The land-use restriction must respect this classification. Following this ranking we will be able to decide which slope to monitor and when to start and stop monitoring the landslide.

The Geological Survey of Norway has already developed a similar method to define the landslide risk on the national territory (Hermanns *et alii*, 2013).

The Norwegian risk analysis is built on a qualitative hazard analysis and a quantitative consequence analysis. The Norwegian analysis is useful to define the slope to manage and to decide the finality (cognitive or early warning) of the monitoring system. In Italy we could use the Norwegian analysis as an example to improve our own.

CONCLUSIONS

The international scientific papers show as slope failure are widespread in all Europe but especially in Italy (Herrera *et alii*, 2018; Iffi, 2021).

To reduce the landslides risk, it is not possible to act in all the areas with structural operations. For this reason, the geological monitoring networks (essential portion that constitute an EWS) represent efficacious and cost-effective means to protect the populations.

This paper shows the Lombardy experience on the field of monitoring and warning service (UNISDR, 2006). Here, in the last years, ARPA CMG have installed and managed many landslides' monitoring networks to issue early warning, as essential tools for risk reduction.

In particular, the GMC of ARPA Lombardia has developed a project focused on the unitary management of many early warning monitoring networks. The unitary management will allow to take advantage of the typical features of economies of scale.

Previously the financial outlay for hardware, software, instruments and equipment stockpile, motor vehicles, offices, activity, and professional training of the technicians was split up on a lot of networks. Therefore, the financial outlay, which would have been required for every single network, is lower (from 18% to 58% as highlighted in the "Discussion" paragraph).

Further benefits of unitary management were in the specialization and organization: technicians who analyze data values or design monitoring networks, maintenance operators, technicians or mountain guides who carry out manual measurements, have greater specialization linked to increased experience.

The specialization is necessary to manage suitably and quickly complex situation like the acceleration of a landslide.

The efficiency of the unitary management of a landslide network in reducing the risk was proved during Gallivaggio's landslide's acceleration (spring 2018). In this situation the CMG was able to alert the Civil Protection some days before the failure. Thanks to that this it was possible to evacuate the area and stop the traffic circulation saving potentially many humans lives.

A further advantage is the chance to handle a single contract to build many geological monitoring networks, instead of one for each network; this saved a lot of time (public proceedings in Italy are usually long).

On the other hand, each single item of the networks has to be perfectly planned (modality of data values acquisition, registered and analyze data values...) for the unitary management of many early warning monitoring networks. The goal of this planning is not only focusing on the single network but also on the unitary management of dozens of networks.

What carried out by ARPA Lombardia in relation to landslide monitoring, represents a unique experience in Italy and certainly with few similar examples in Europe, both for the number of networks managed unitarily (44) and for the data (about 25 million) acquired and analyzed every year.

Finally, the benefits on risk management, as in the case of Gallivaggio, and in compliance with European (Bazin, 2012) and Italian (Dei Cas *et alii*, 2021b) guidelines, show that unitary management of landslide monitoring networks is the ideal method to manage landslides and reduce the problem of the danger of landslides.

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