Environmental risk analysis for telecommunication networks

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Abstract

This work presents a new methodology to assess the problems that soil instability and river floods may cause to Telecommunication (TLC) network infrastructures.

The methodology was applied in a selected area of South Piedmont hit by a disastrous event on November 1994 when landslides, floods and bridges collapses caused many damages to TLC network infrastructures. The hazard conditions have been defined through thematic maps about flood areas, landslides, lithology, geomorphology and depth of water table using Geographic Information System techniques (GIS).

The results obtained, synthesised in a thematic map of risk conditions, are very helpful in planning the management of network and its future development, taking into account territorial problems.

Introduction

Telecommunication networks infrastructures can be considered "high technology" networks due to their technical characteristics and to the complexity of the service offered.

Actually, millions of kilometres of cables for telecommunications are posed through the territory. TLC cables are linear infrastructures crossing different portions of the territory and hence can be affected by natural phenomena as floods, landslides and earthquakes. Natural phenomena may seriously cause strains on the TLC cables through mechanical stresses, such as traction, shear, contact with the water and erosion. These facts force the cables to work out of their technical and functional specifications. For this reason it is important to develop a Linear Infrastructures Risk Assessment (LIRA) methodology able to reveal in advance critical infrastructures situations, from the natural hazards point of view.

The LIRA methodology described for the first time in the present work, is a powerful procedure to manage ordinary and extraordinary interventions on the existent TLC network infrastructures and to plan future ones in order to reduce damages and economic losses.

In particular we have focused our study on the optical cable network because of its technological importance and the more and more large use in the TLC.

Methodology

The purpose of the method used is the **risk** evaluation. Risk is defined as the expected loss, due to a particular natural phenomenon, in a given area and period of time [1], [2]. It can be quantified through the result of three risk factors [3], [4]:

- **Hazard** (H), the probability of a potentially destructive natural phenomenon of a certain intensity occurring in a given time and in a given area having determined evolutive modalities;
- **Vulnerability** (V), the probability that the stress induced by a natural phenomenon characterised by a determined magnitude forces optical network to work out of functional and installation rules;
- **Importance** (I), the economic and strategic worth of the elements exposed to potential hazard in a determined area.

The study starts with the acquisition of land and network data from various archives such as regional, municipal, research centres, private, etc. Data can concern thematic maps (flood areas, landslides, lithology, water table) and historical information.

The choice of the analysis scale should consider the purpose of the study, the availability of the land data and the geo-morphological characteristics of the studied area [5]. In this study, a small scale (1/100.000) was used. This scale allows a synthetic representation of large portions of land permitting a macroscopic highlighting of natural phenomena.

The LIRA methodology takes into account only natural phenomena able to interfere with the analysed network structure.

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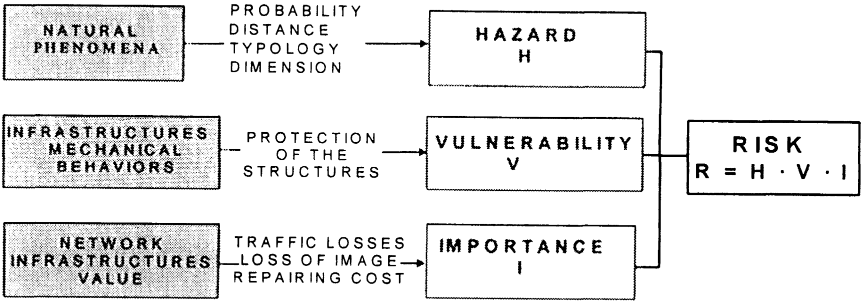

Figure 1. Risk Assessment: main parameters.

Then it is necessary to attribute a "pertinence zone" (PZ) to each part of the cable. The PZ is the area surrounding the network having a lateral extension, mainly function of the geomorphology; for instance, in the present study the width of PZ was 1km. at each part of the cable.

The optical network was positioned on a topographic map, and then all the thematic maps have been over-placed by means of a georeferentiation process.

The considered parameters for the determination of the risk having the greatest influence to determine the three risk factors hazard, vulnerability and importance are schematised in Fig.1.

The various parameters that contribute towards the determination of the single risk factor are generally evaluated by means of different measurement units. In order to compare the non-homogeneous parameters, a "score method" was used and a relative measurement scale was defined [6]. Parameter ranges were sub-divided in classes, and a score was assigned to each class. The single risk factor value was obtained by multiplying the related different parameters score.

The sum of the maximum hazard, relative to each type of natural phenomenon interacting on the optical network segment, multiplied by cable vulnerability and importance, finally leads to the evaluation of the single segment cable risk index. Final results of this analysis therefore allowed us to indicate the network segments characterised by a greater environmental risk, according to a limited number of risk classes.

Application of the methodology to a sample area

A sample area was chosen in order to calibrate the methodology on a real case and to compare the obtained results with the network real situation.

The area of Southern Piedmont, between Asti, Alessandria and Cuneo was hardly affected by the flood of November 1994. For this reason this area has been chosen as "case study" area.

Inside the chosen area, the overflowing of both main river, the Tanaro, and minor hydrographic networks is the main natural phenomenon affecting the plain area, in the case of a flood event, while the hilly areas are affected by shallow and deep landslides.

Data Acquisition

The high number of land data and the complexity of the relative elaboration, require the use of informative instruments GIS (Geographic Information System). GIS are able to carry out a spatial type analysis, run databases and prepare synthetic cartography.

In particular, the ESRI ArcInfo 7.04 PC version, for workstation (WS), was used to carry out the study for georeferentation and analysis of the data. The ArcView 3.0 version, with the Spatial Analyst modulus, was used for the visualisation of starting data and final results.

The sources of TLC network and territorial data [7] are synthetically described in Fig. 2, while their process acquisition in Fig. 3.

As shown in Fig. 2, cartography representing the reference situation ("state of nature") consists of a group of thematic maps often having different scale and format (available in numeric or paper format).

Maps only available in paper format were digitised in order to obtain homogeneous reference database. Import-export operations with .e00 file format were used to move and acquire numeric data.

Once the data were inserted on the WS, they were transformed in GIS layers and georeferenced. Georeferentiation procedure was done only for some maps, manually realised assigning the earth's co-ordinates to some notable points.

Various maps (maps IGM 69-70-81-82, Regione Piemonte) were placed side by side and joined together in order to have a unique map for the whole sample area in relationship to each thematism (e.g. streets, landslides, floods, etc.) considered.

An important GIS operation consists of assigning spatial co-relations between numerical objects. This operation, named "topology construction" was done using particular GIS commands (e.g. *build* and *clean* in ArcInfo).

Finally the ArcInfo repeated instructions were usually assembled in macro-instructions (Aml, *Arc Macro language*), in order to simplify their execution.

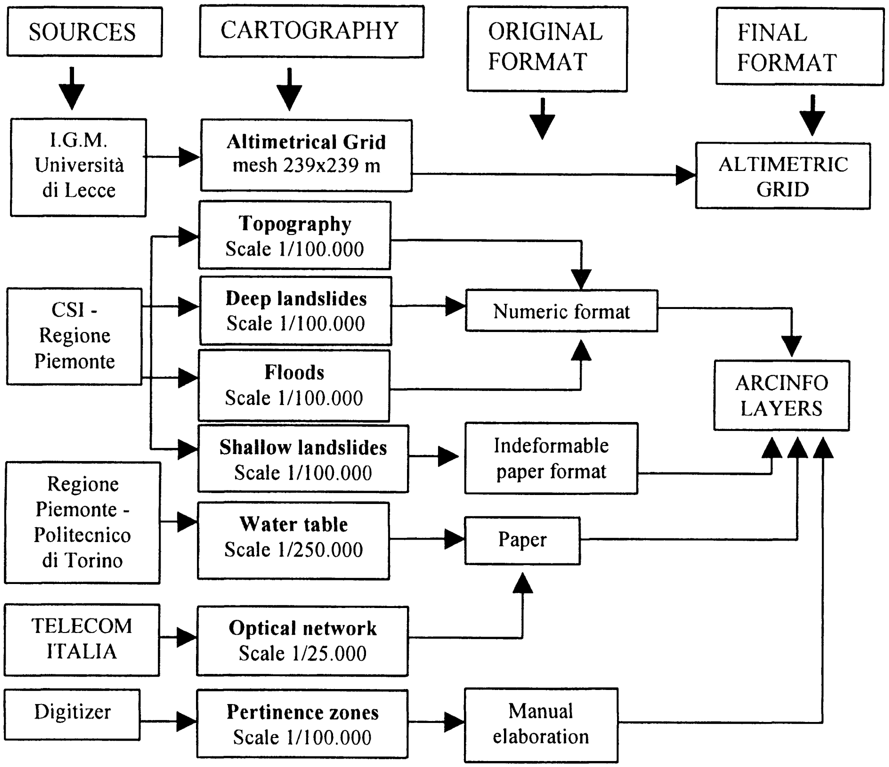

Figure 2. Data Acquisition.

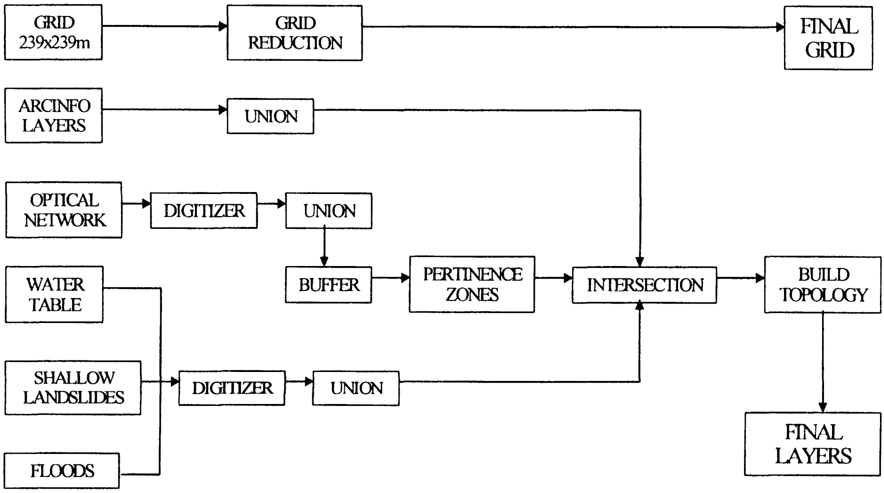

Figure 3. Acquisition Process.

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Data Analysis

The first step of data analysis was to calculate the hazard. This risk factor can be expressed in several significant parameters representing, for the different phenomena, the characteristic, behaviour and the potential interaction with the TLC infrastructure.

The list of the main parameters, obtained by means of this elaboration, is shown in Table 1. In Fig. 4 the steps of the elaboration regarding the shallow landslides have been summarised. Other natural phenomena have been elaborated in the same way.

The elaboration of the parameter "direction" for shallow landslides is in the following explained in detail as example.

The maximum slope vector named "moving direction vector" (MDV) identifies for each landslide its movement. The landslide movement intensity effect on the optical cable was obtained evaluating the angle between the MDV and the cable direction vector (CDV), representing the local direction of the cable referred to the northern direction). For all landslides, the set of angles obtained has been assigned to four classes of values. The perpendicular direction between these two vectors, MDV and CDV, has been assigned to the higher level class because this angle represents the maximum intensity effect.

The evaluation of direction parameter required the development of several procedures allowing the identification of the watersheds crossing the parts of the topographic slopes characterised to shallow landslides. In effect, in the cartography used watershed position is not available. As the shallow landslides concerned only the parts having slope effectively insisting on the infrastructures network have to be considered. In order to

Table 1. Natural phenomena and their characterising parameters.

Natural phenomena	Parameters to quantify hazard
Shallow landslides	• Areal extension • Maximum slope degree • Direction • Minimum distance regarding the cable
Deep landslides	• Volume • Landslide typology • Direction • Minimum distance regarding the cable
Floods	• Frequency • Deposit type • Interference with infrastructure
Underground layers	• Depth > 2m • Interference with infrastructure

evaluate the watershed crossing the shallow landslide areas, a statistical analysis of the "local movement direction vectors" (LMDV) have to be taken into account.

The LMDV have been evaluated by a sub-division into cells of the whole landslide area, using altimetrical grid and applying to it an ArcInfo command. The command *aspect* computes for each cell the angle between local direction and geographic North.

A statistical analysis of the direction angles allowed us to identify landslides with a discontinuity in movement direction.

The MDV for the single shallow landslide was calculated as average weighted of the LMDV.

Risk Analysis

A set of classes was then associated to each parameter. In order to compare classes of different parameters a score was given, as shown for the shallow landslides in Table 2.

Numerical value of hazard factor was obtained multiplying different scores assumed by different parameters. The same procedure can be used

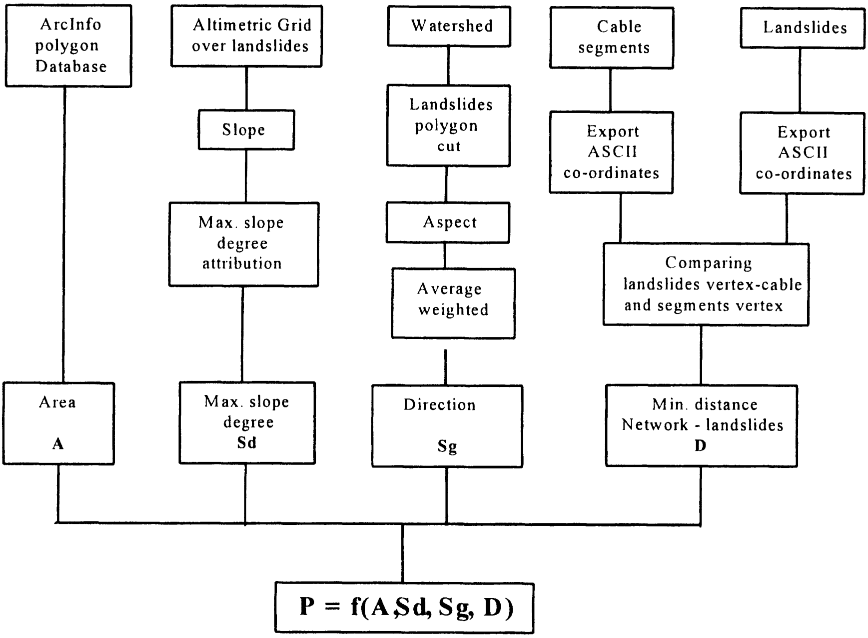

Figure 4. Shallow landslide elaboration.

Table 2. Shallow landslides: example of "score method" application.

PARAMETER	VALUE	CLASS	SCORE
Direction	opposite	0	0
	parallel	1	0.3
	slanting	2	1
	perpendicular	3	2
Slope [°]	< 7°	1	0.7
	7° - 14°	2	1.3
	>14°	3	2
Area extension [m²]	< 100.000	1	0.7
	100.000 – 300.000	2	0.9
	> 300.000	3	1
Minimum distance [m]	> 300	1	0.7
	60 - 300	2	2
	< 60	3	3

to evaluate vulnerability and importance risk factors.

The obtained "risk index" map [8], shown in Fig. 5, represents a synthesis of such elaboration. The index has been subdivided into 5 classes of values, in relationship to the maximum and minimum levels of risk.

As shown in Fig. 6, a further statistic elaboration was carried out by the analysis the percentage of the cable directly involved by each phenomenon in relationship to the whole cable length. In particular, the part of cable involved in landslides has been related to the width of the landslide area projected on the cable, while in floods to the cable length crossing the flood area.

Conclusions

For the first time a methodology for the linear infrastructures risk assessment (LIRA) was applied to TLC lines such as the optical cables network. LIRA methodology was used to draw up the optical cables risk maps.

This kind of cartography allows:

- to individuate the portion of network in the most hazardous territorial situations;
- to manage the critical situations in order to prevent damages;
- to improve the monitoring control in the most hazardous areas;
- to integrate the risk maps in warning devices.

Furthermore the worked out cartography is useful in planning new TLC network characterised by minimum risk related to natural phenomena. The future developments on LIRA methodology aim to apply the procedure to other geographical areas including other types of natural risks as earthquakes, volcanoes, etc...). Moreover the risk factors "Vulnerability" and "Importance" have to be deeply analysed in order to well defining the constituents parameters. Another important aspect for further development of the methodology is to take also into account the "triggering factors", such as the meteorological events, in order to use a probabilistic evaluation.

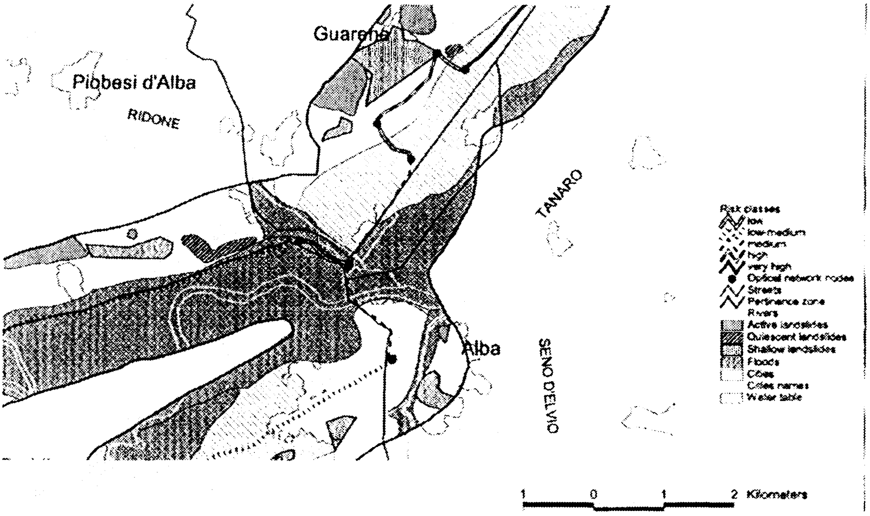

Figure 5. Portion of thematic map showing different risk level of the optical cable.

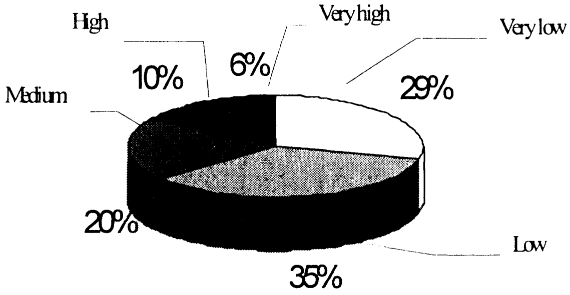

Figure 6. Statistical elaboration of risk level of the studied area.

Finally it is important to point out that this approach could be also applied to the others technological linear infrastructures such as pipelines, gas and electricity distribution networks.

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