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A multivariate method for estimating the existence of cryptic archaeological sites at infrastructure works

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Abstract. A parametric spatio-temporal model for facing the risk of exposure of cryptic archaeological sites due to large infrastructure projects in rural areas is presented. It works under budget constraints in the information market, and is useful for making decisions on the control of environmental systems. After characterizing and measuring the main variables that describe the probability of the existence of any site in an area where works are projected, a function is generated through an artificial neural network or some other statistical process to find these probabilities in each zone of the rural area. The method provides cartography with probabilities of existence of archaeological sites, a useful tool for choosing the best location for the planned infrastructure. This method of non-invasive prospecting of archeological evidence, reduces the cost of information gathering to one third of traditional methods and provides probabilities with satisfactory accuracy.

Keys words: artificial mind, cryptic archaeological sites, environmental systems, probability, costs.

1.- Problem

Many developing countries have assumed as state policy the construction of public infrastructure as fundamental capital in productive processes. Ports, airports, bridges, highways, and tunnels are some examples of infrastructure that are indispensable for regional development, but due to the magnitude of the construction of these kinds of infrastructures, environmental alterations occur in the area where they are situated [1]. Many of these environmental impacts are perceived as negative, because they deteriorate natural and cultural patrimony elements [2].

One of the elements exposed to deterioration during the construction phase of large infrastructures is archaeological patrimony [3]. In fact, experience shows that the use of heavy machinery, particularly during land movements, tends to cause direct destruction of these hidden evidences of ancient human activity [4].

In general, as a preventive measure, the area in question is prospected or surveyed to identify possible archaeological sites, in order to subsequently remove them from the project area, or modify the project's layout. This *in-situ* activity has the disadvantage of a separate survey for each alternative project location [5]. Such extensive surveying requires a great deal of capital, sometimes making the project unfeasible because of budget restrictions. Of course, the main costs are the wages of archaeologists working in the countryside [6].

Some artificial systems have been proposed for solving these problems, most of them are Computer Aided Engineering [7]. However, none of them work under scarce information and scarce budget conditions, so construction companies and governments are not able to make better decisions in terms of environmental studies in early stages of projects.

Nevertheless, recent advances in spatio-temporal information management enable a better understanding of the project area, allowing planners to estimate the cryptic goods contained therein; without invasive techniques. Possibilism offers to reach this goal by the way imitating the role of the intellectual capacity of archaeologists, one of the more expensive productive factors in the study phase of projects in rural areas.

2.- Objectives

The general objective of this investigation is to design a cheaper method that allows the quantification of the risk of archaeological patrimony due to different layout alternatives for large road or infrastructure works. This method must avoid the main costs of the traditional survey system [8].

3.- State of art

What is an archaeological site?

Even though there is no international consensus regarding a definition, an archaeological site can be defined as any portion of a space that contains any testimony of human activity in a previous time relative to some nearby historic event. For example in Chile, the arrival of the Spanish conquerors is often considered to be the historic event.

In this context, archaeological sites can contain fortresses, workshops, kitchens, hearths, tools, sculptures, paintings, or weapons, among others. These sites can also be constituted by human remains such as cemeteries, excrements or waste from past productive activities.

According to current knowledge, in an infrastructure project there are two types of archaeological sites: conspicuous and cryptic. The first type is evident and therefore generally well surveyed and rescued during previous researches. The second type is hidden, buried under earth or covered by vegetation; and its existence is not known before the project is carried out.

Why take care of archaeological sites?

This is a question that any contemporary society innately needs to consider. The answer, regardless of the local institution, relates to the information that comes from these sites. This information comes from a distant past that helps society understand the present and project the future.

If some archeological site is destroyed, some information about past events will be lost. In other words, when a current project destroys an archaeological site, an environmental detriment occurs.

What kind of information can an archaeological site provide?

Depending on the content of an archaeological site, it can give an account of the biological and/or cultural behavior of ancient societies. The information can comprise from the body size of an individual to the vision that he had of the world. For example, the remains of an ancient cooking area can not only indicate the human diet and the techniques for using fire, but it can also give information about the environment in which the plants that were used for burning grew.

What archaeological sites should necessarily be considered under environmental control?

Since ports, airports, tunnels or highways are immovable goods; these types of sites must be necessarily considered in environmental studies because they “compete” against the immovable archaeological sites for the same space. Indeed, a site with movable elements (arrow tips or pottery, for example) can easily be rescued during the construction of the project if such artifacts are discovered. The opposite situation occurs when ancient buildings are discovered (temples or fortresses, for example).

The situation today

As stated earlier, the objective of this research is to provide a less expensive method than the present traditional archaeological surveys and also reduce the uncertainty to a level similar to that of the current technology used for these purposes.

The current technology consists in an evaluation of the site where the project will be carried out. This evaluation involves costly work: topographic, soundings, laboratory tests, and others. Such surveys are expensive activities, particularly when specialists must search for hidden information, generally covered by earth and/or vegetation. The need to carry out costly work decreases if the team of specialists is experienced. The documentation and use of such experience can reduce the number of surveys and therefore the total cost of the study.

4.- Method

A method that manages such expert knowledge is called NMD. Indeed, NMD is quantitative and considers the following steps: a) characterization of a finite group of variables that explain the probability of the existence of a site; b) cartographic fragmentation in homogeneous geographic units of the area affected by the project, where the behavior of the explanatory variables within those units can be considered uniform; c) identification of geographic units similar to those considered by the project in question, where there already is a register of the explanatory variables and probability values; d) design of an artificial neural network or of another tool that relates multiple variables, in order to discover the explanatory function with the available registers; and e) entry of the observed explanatory values of the variables into the function, for each geographic unit of the project space where the probability is sought.

These phases are described below for a case study in a prealtiplanic zone in the north of Chile, where the existence of archaeological buildings sites such as temples, cemeteries, fortresses, houses, and others is investigated.

4.- Results

4.1.- Economic aspects

As mentioned in the Problem of this paper, a new method should be designed (NMD in what follows) to quantify the archaeological patrimony in the early phases. It should cost less than a land survey or other traditional methods which need the actual presence of specialists in archaeology. This is not the only budget constraint in the conception of NMD, because any method that quantifies the compromise of the archaeological patrimony should have lower costs than the commitment itself.

In fact, considering that an infrastructure project may cause damage to a place of interest, the preventive measures, which include the method of quantifying such cultural resources, should have a lower value than the resource itself. In common terms, it is not new that “the medicine should be cheaper than the illness”. Therefore, another budgetary benchmark higher than NMD is identified.

Summarizing, if T is the cost of a traditional land survey of an archaeological site and D is the cost of destroying the site partially or totally, the cost of NMD represented by C should be:

$$C < \min \{T, D\} \qquad (1)$$

The value of T is known and depends on the current market conditions, where the main components are the professional services of the designated archaeologists. But the value of D is difficult to quantify due to the fact that in many societies archaeological sites are not formally valued. Therefore, if the value of the resource is not known, it is impossible to determine its devaluation due to a destructive action.

A representative variable of the value of archaeological patrimony is usually the price, which doesn’t exist clearly in many societies because of:
-There is no explicit market, because sale and purchase in any form is prohibited.
-There is no clearly defined owner because it is assumed that it is the property of the entire nation.

Fortunately, it is possible to obtain a value of the archaeological patrimony as a function of the information that it contributes. As mentioned in section 2.1, archaeological sites are protected because they are a source of information from the past. Therefore, if the value of the information that they contain is determined in monetary units, then the values of these sites can be estimated in the same units.

Therefore, the problem is reduced to determining the value of the archaeological information. In this context and based on the economic principle that the more scarce an asset (good) is, the more valuable it becomes [9], a relation can be found between the information from present and ancient societies. Since the value of the information from the present is known, with such relationship supposedly reversed the value of the past information can be obtained. Mathematically, the simplification is as follows:

$$\frac{\text{Quantity of information about present}}{\text{Quantity of information about past}} = \frac{\text{Value of information about past}}{\text{Value of information about present}} \quad (2)$$

The terms on the left side of this equation can be estimated through surveys concerning the perception of the uncertainty level of past and present phenomena. On the other hand, the denominator of the right hand term is set by the market, through the prices meant to generate information of the present. Therefore, the numerator of the right term can be obtained solving Equation 2.

As an example, Figure 1 shows the perceptions of different citizens from the province of El Loa in Chile, about information through arbitrary time periods. Of a total of 122 people surveyed from this location, it is seen that the relation between quantity of information about the present and quantity of information about the past is 5800. In fact, the average of the curve since the arrival of the Spanish to the present (87,000%) is 5800 times larger than the average of the rest of human settlement (0.015%). Therefore, for this particular case the information about the past should be 5800 times more valuable than that about the present.

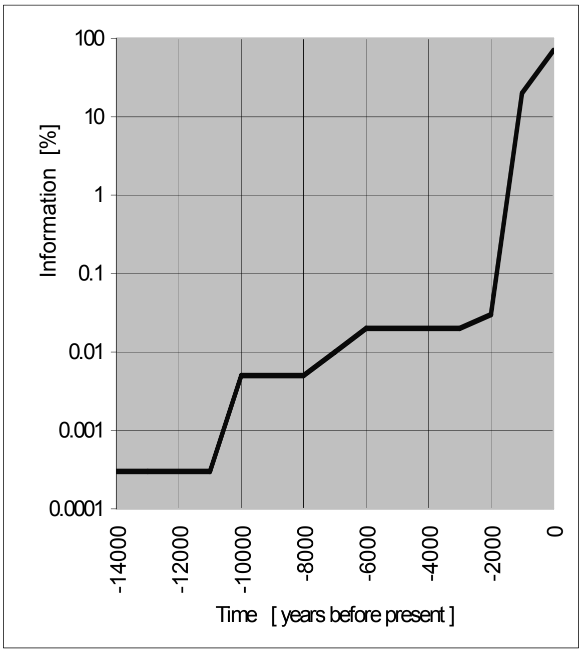

Figure 1: Perceptions regarding the quantity of available information.

Another example can be seen from applying Equation 2 to the Atacama desert: on the average, the communities of Chiu-chiu (a town in the province of El Loa) and other local residents estimate that the information about the present is five times greater than that about the past. In other words, the information about the past is therefore five times more valuable. Therefore, the resources used to investigate past phenomena should be five times more than those used to investigate present phenomena. Does this really happen?

To answer this question, the universe of the phenomena to be investigated must be limited for the past as much as for the present. Since archeology is interested particularly with human past, the comparison should be referred to humans in the present. After examining two dozen environmental impact studies from the same number of environmental services, it can be concluded that the price of description of the Present Human Medium is almost 25% of the price paid for the Archeological section of the study. That is, the relationship is four times greater, which is relatively near the theoretical value indicated in Equation 2.

From this, the value of T in Equation 1 can be deduced, in the understanding that the cost of a traditional archaeological survey is not prone to large distortions. In other words, the market price that is paid at present is close to perfect competition [7].
Therefore, society can avoid paying a patrimonial cost D, asking for such a survey. That is to say, the cost of a traditional land survey of an archaeological site is similar to the cost of destroying the site (T ≈ D).

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4.2.- Aspects of information

Characterization of the explanatory variables

Since in the project zone human occupation was carried out by *Homo sapiens* [12], it is assumed that the natural conduct pattern of such an occupation corresponds to that of the current Chilean occupation, even though it was materialized more than 15,000 years BP (before the present). Considering these arguments, the explanatory variables are the following:

X1 = Linear Density of Permanent Water Sources km/ha]. Greater availability of water, evident from the number of estuaries, rivers, and lakes; indicates a greater probability of human presence because of the existence of this vital resource [16]. The value of the variable is the quotient between the sum of the perimeter length of all the water courses and the area of the geographic unit.

X2 = Potential Productivity of Vegetation Resource [kg/m²/year]. This variable estimates the development of vegetation given certain qualities of the physical environment, linking the climate with the flora, based on average temperatures, precipitation, and evaporation rate. Greater abundance of vegetation indicates greater probability of buildings because of the associated food chain and the supply of structural material.

X3 = Percentage of Consolidated Formations [%]. The availability of lithic materials (stones, rocks) was fundamental for the construction of buildings [18], because the greater abundance of such materials is associated with greater probability of building.

X4 = Distance to a source of water [km]. It is supposed that human settlements tend to exist near permanent water sources.
If this distance increases, then the likelihood of building decreases.

X5 = Anthropic Index [%]. The more altered and disturbed the environment is by human actions, the lower the probability of conservation of archaeological ancient buildings [6].

Notice that five variables have been identified from former studies about the region of interest. These variables will be stored in the NMD.

Cartographic fragmentation

The zone that is potentially occupied by the project and the different alternatives is fragmented into small cells or micro-regions, where it is supposed that the spatial behavior of the explanatory variables is homogeneous.

Figure 2 shows an example of a cartographic fragmentation in several units with two alternative routes: north and south, to link two points. The different tones in each unit represent similar geographical characteristics inside these micro-regions.

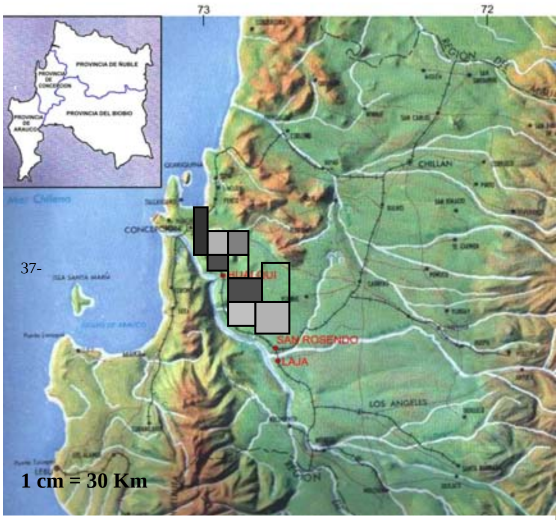

Figure 2: Example of cartographic fragmentation with different units showing their probabilities. The dark tones represent higher probabilities than the light ones.

Getting a register of Xi and P from secondary sources

Based on secondary sources, including previous projects where the behavior of the five explanatory variables is known, and where the probability of existence of sites is known through their frequency per surface unit, an observations matrix is constructed as shown in Table 1.

In this table, the magnitudes of X1, X2, X3, X4 and X5 are known, as is the Probability P of existence of an immovable archaeological site**.**

Table 1: Observations in eight spatial units

Unit	X1	X2	X3	X4	X5	P
1	0,3	0,4	0,6	0,6	0,6	0,44
2	0,8	0,9	0,9	0,2	0,4	0,64
3	0,2	0,6	06	0,2	0,3	0,38
4	0,2	0,2	0,2	0,2	0,3	0,22
5	0,2	0,6	0,6	0,2	03	0,48
6	0,7	0,6	0,6	0,2	00	0,42
7	0,7	0,6	0,6	0,0	1,0	0,58
8	0,3	0,1	0,0	0,5	0,2	0,32

4.5 Search for the function

Data

The observations from Table 1 are used as data to feed a multivariable method. In this case an artificial neural network that delivers a linear function through the parsimony principle [13]:

$$X1*0,2+X2*0,3+X3*0,1+X4*0,2+X5*0,2=P \quad (3)$$

In the function, the magnitudes of X1, X2, X3, X4 and X5 are normalized entries.

Entry values to the function

Finally, in the project zone, for every cell the quantities of interest from X1 to X5 are measured. They are entered into the linear function of Equation 3 to obtain the sought probability. For instance, if the darkness of the units in Figure 2 represents the probability obtained from Equation 3, the best route would have been the north line because it crosses the micro-regions with smaller P.

Test

To test the performance of this method, it was applied to a projected bypass in Chiuchiu, reducing the cost of the Archeology Section study in the preproject stage to one third compared to a traditional archaeological survey, and delivering a precision equal to that required in projects that consider different alternatives. Besides, the results have encouraged some Chilean companies to use this method, achieving better environmental studies [14].

5.- CONCLUSIONS

The present research and application provides number conclusions, some of them economic and others dealing with information. The economic conclusions are the following:

- Archaeological cryptic sites are valuable to a society because they can reduce the uncertainty that exists on their past. The most important cryptic archaeological sites in infrastructure works are buildings, because such sites and the project demand the same vital space.

- Currently, a professional kind of service exists to transform the cryptic state of a site into a conspicuous state. It consists in a traditional archaeological survey. Such types of services in infrastructure works scenarios are traded in a market of almost perfect competition. These traditional methods are expensive, especially in zones with difficult access and few facilities.

- An alternative method is developed with a cost lower than one third of the cost of a traditional survey, generating an imperfection in the market and therefore an opportunity for business at the pre project stage. This method is a new tool to improve the control of environmental system, especially when the current infrastructures are putting ancient infrastructures at risk.

Finally, the data processing conclusions concerning informatics are the following:

- Artificial neural networks for solving patrimony problems are not a novelty, but their use as a statistical method to quantify the existence of valuable ancient sites is a new and useful tool in environmental impact studies.

- The secondary sources represented by previous studies provide a universe of explanatory variables of the existence of archaeological sites, groups of data, and other expert knowledge concerning the patrimonial alteration.

- The expert knowledge allows the creation of a kind of artificial mind that discovers the probability based on the explanatory variables.

- Since the probability in question depends mainly on five easily quantifiable variables, the results are obtained with a precision of 15%.

- That precision is satisfactory in the case of an archeological building in relation to an infrastructure project, allowing the alternatives of modifying the project layout or rescuing the archeological findings, among other decisions.

- Finally, this method imitates the mind of the ancestors who produced some material testimony in their territory. In fact, knowing the environmental variables in the zone of interest, it is possible to guess how the earlier inhabitants thought and to assume their preferences about the location of the ancient activities.

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