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An expert system for the identification of environmental impact based on a geographic information system

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ABSTRACT

The identification and assessment of the environmental impacts of engineering projects is an essential step in studies on environmental impact (IES). There are methods that allow both tasks to be performed and methods that allow each of them to be carried out separately. Normally, traditional methods are used to identify and evaluate environmental impacts, such as matrices, cause-effect network diagrams or check lists. Here we report the configuration of an expert system as a tool that allows environmental impacts to be identified. The expert system is based on a geographic information system to configure the knowledge base, the inference motor and the user interface. The knowledge base comprises declarative knowledge (structured in an alphanumeric and spatial database from official cartographic information) and procedural knowledge (via heuristic rules that superimpose project actions over environmental factors). We then describe the application of the expert system to the study of the environmental impact of the R-3 motorway in the Community of Madrid, Spain. As results, running the expert system allows the identification of environmental impacts on environmental factors defined at the 1:5000 and 1:25000 cartographic scales. Finally, analysis of the results or conclusions allows the validity of the use of graphic expert systems to be compared for the identification of environmental impacts.

1. Introduction

1.1. Background

This work is related to two avenues of enquiry: on one hand, the use of computer-generated models and the development of software for the identification and assessment of environmental impacts and, on the other, the application of geographic information systems for the identification and evaluation of environmental impacts.

Within the context of research into models and software development, the first IMCA (Gómez-Orea et al., 1990) and IMPRO (Gómez-Orea et al., 1991) models are very important, as is the later improvement with the IMPRO 3 (Gómez-Orea, 1999). In this sense, emphasis should also be placed on the proposal of a "Metalanguage for the Evaluation of Environmental Impact" (Pereira, 1999) or "AIEIA: software for fuzzy environmental impact assessment" (Blanco-Morón et al., 2009). Regarding the application of GIS to the identification and assessment of environmental impacts, contributions addressing the role of the spatial dimension of environmental impact and the assessment of their importance are relevant (Antunes et al., 2001; Vanderhaegen & Muro, 2005).

As well as the above research framework, this work also addresses the following issues: (1) the strong dependence of the assessor (or expert) in the identification of environmental impacts by the methods usually employed to measure them (matrices, network diagrams, check lists); (2) the spatial issue is not addressed in traditional methods assessing environmental impact (in this sense, the actions of projects are not usually represented cartographically, neither are comparisons found between situations "with" and "without" projects by cartographic representation); (3) the elaboration of digital cartographic information in a study addressing environmental impacts is costly.

1.2. Hypothesis approach

In light of the foregoing, the present research aimed at the configuration of an expert system able to identify environmental impacts. To accomplish this, it was necessary to consider the spatial component of the environmental information. To do this, the actions of the project, and the environmental factors were represented cartographically and "with" and "without" project situations were analyzed by means of a geographic information system (GIS). Additionally, the cartographic information about environmental factors came directly from numerical cartographic bases or cartographic series in digital form elaborated by the corresponding official cartographic agencies.

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2. Configuration of the expert system

An expert system has three main components: a knowledge base, an inference engine, and a user interface. In turn, the knowledge base is formed by declarative knowledge (i.e., about facts) and procedural knowledge (i.e., about procedures for searching or actions). Declarative knowledge is stored in databases. In the present case, declarative knowledge was the information contained in both the thematic and spatial databases of the GIS. Evidently, the information of both the thematic and spatial databases must refer to both the project and the environment.

Procedural knowledge should contain the procedures that allow environmental impacts to be identified from actions in the project and environmental factors. The most advisable type of representation of knowledge for our expert system was rules, also known as "heuristic rules".

The inference engine allows a series of rules, but not others, to be used. Finally, the user interface allows two-way interaction between the computer and the user.

The heuristic rules that allow environmental impacts to be identified by the expert system were based on three essential relationships of the project and the environment (Gómez-Orea, 1999): (1) the project is located in space; that is, the environment supports the project; (2) the project extracts, consumes, or uses resources from the environment; i.e., the environment is the sources of materials and resources; (3) the project emits effluents, residues and contaminants into the air, water and soil; that is, the environment receives contaminating agents from the project and disperses, filters or purifies them.

The above relationships demand that three types of action, environmental factors and environmental impacts be distinguished. These three types of relationships are shown in Table 1.

2.1. Declarative knowledge

As mentioned, declarative knowledge is knowledge about facts. This knowledge is stored in a database. In the hypothesis formulated, it was considered that declarative knowledge was stored in both the graphic and thematic GIS database. Evidently, the structure of the thematic database will be relational and the tables and relationships between them will depend on the GIS adopted in the verification test.

Moreover, the information about the environment should be at different graphical scales in order to be able to identify environmental impacts that are verified at different scales. The cartographic information of the project demanded a description of the different location alternatives expressed with the level of detail corresponding to the decision level at which the proposal for action was found.

Regarding the types of action and environmental factors mentioned above, let us now see how each of them is represented.

2.1.1. Type of project actions

From the topological point of view, the different activities of the project can be considered as follows.

The actions or elements of the project that occupy or transform space will normally have a specific extent. Accordingly, it was agreed that this type of activity would necessarily be defined by polygons. It was necessary to specify whether (a) this involved direct destruction of all the environmental factors present on the ground and in the air (the case of the construction of buildings and infrastructures); (b) it involved the direct destruction of some environmental factors (not all) present on the ground, except water and air, and (c) it did not involve the destruction of any environmental factor, but led to a change in land use.

The actions of the project that specified the extraction of certain resources required that the following should be determined: (a) the site of capture or extraction of the resource (defined topologically as a point or a polygon); (b) the trajectory of the transport or distribution of such a resource (defined topologically by a line), and (c) the site of consumption or use of the resource (defined by a point, a line, or a polygon).

The actions of the project that required the emission of effluents were also defined as points, lines or polygons, depending on whether one is dealing respectively with point-like, linear or diffuse sources. Similar to the actions involving the extraction of resources, the emission of effluents required the following to the determined: (a) the location of the initial source of emission, which may be at a specific point, linear or superficial, and whether the emission was directed into the air, the water or the soil (it is also possible to specify the type of contaminating agent – physical, chemical or biological); (b) the geographic extent or area of influence of the effect brought about by the dispersion and mobility of the pollutant in the air, water or soil (the greatest mobility is seen in the air and in the water, both surface and underground). In the case of the soil, two cases may appear: one in which the contaminant is not dispersed (the pollution was delimited geographically by the source of the emission) and another in which the polluting agent was dispersed by the infiltration and mobility of groundwater (in which case an area of influence is generated.

2.1.2. Types of environmental factors

Likewise, from the topological perspective environmental factors were defined as follows. The environmental factors that were affected by the location of the new activities depended on the destructive nature of the activity, as seen above.

If the activity involved the construction of an infrastructure or building, this involved the direct destruction of the environmental factor present on the ground (except the water and the air). Accordingly, the environmental factors affected were the gea (polygon) the geomorphology (polygon), the soil (polygon), the vegetation (polygon), landscape (polygon), land use (polygon), settlements (polygon), and infrastructures (points, lines and polygons). If the activity involved the destruction of some environmental factors present on the ground, land use (polygon) and the corresponding environmental factor or factors were modified, and if the activity did not destroy any environmental factor, only land use was modified (polygon).

The environmental factors that acted as resources of the project and that were useful from the point of view of the identification of the environmental impact were: (a) non-renewable resources that were consumed through their extraction. This mainly refers to soils and minerals (mining exploitations); that is, gea (quarries, mines), the soil (gravel pits) and the geomorphology (gravel pits and quarries). This resource was defined as a polygon; (b) renewable resources, mainly water (irrigation, water services, for example), both surface and underground. This factor was defined with a point (springs, wells), a line (streams and rivers) and polygons (reservoirs, lakes, etc.).

The environmental factors that received the effluents directly from the project were the air, water and soil. Air was not represented topologically in the system, such that the way it was affected was defined by the space in which it was affected by the pollutant. Surface water was represented by the three basic topological elements. Underground water was represented by points (wells and boreholes) and by polygons (aquifers). Finally, the soil, from the pedological point of view, was defined by polygons.

2.2. Heuristic rules

2.2.1. Identification of impacts by location/space transformation

The identification of an impact by location/transformation was carried out through the following topological analysis: when the