

Integrated landscape management methodology: an application of Bayesian Belief Networks (BBNs) to the UNESCO landscape of the Diamantina (Ferrara, Italy)

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Abstract

The article deals with an integrated landscape management methodology that was investigated in a case study in the Diamantina territory near Ferrara (Italy), declared 'protected landscape' by UNESCO in 1995.

Integrated policies are widely accepted as the best way to achieve sustainable environmental development. The challenge is to develop a practical and effective methodology that enables managers to make multi-objective decisions, while at the same time ensuring that stakeholders become actively involved in the decision-making process: in other words, to implement integrated management. The Diamantina study attempts to provide such a methodology through the development of a generic integrated management tool based on the concept of Bayesian Belief Networks (BBNs). The authors adapt the methodology to the problem of integrated urban management, as support to the renovation of the Provincial Plan of Ferrara.

The specific objectives of the Diamantina case study is to investigate the extent to which BBNs can be used as a decision support tool for urban management and landscape protection, according to the European Landscape Convention (2000). The network was constructed focusing on innovative actions for precautionary landscape protection against risks on the holistic habitats protected by UNESCO.

1 Introduction

Sustainable landscape management has become the complex current challenge to deal with. Multiple domains characterize it, and the knowledge that represents it is made up of the interactions of multiple stakeholders, policy makers, laws, structural and environment elements that compose the synoptic landscape table. The aim is to protect this fragile and dynamic equilibrium from internal and external risks that could destroy it.

Measuring is a precursor to effective management, and operational risk measures are the link between performances fluctuation and landscape activities [1]. So models are used to discuss both scenarios and take action, so as operational tools supporting policy making. In fact a causal understanding is essential in order to take appropriate action and to control and manage risk because causality is a basis for both action and monitoring. Simple cause-and-effect relations are known from experience, but more complex situations such as landscape dynamics may not be intuitively obvious from information at hand [2]. Controllable risk (cause-and-effect one) and uncontrollable risk, that it's defined as those risks that do not usually have causal factors that can be influenced, must also be considered.

Bayesian Belief Networks (BBNs) are directed acyclic graphes of nodes representing variables and arcs representing dependence relations among them. BBNs permit to collect and to structure data from different subjects, representing their influences and describing the system in a non-deterministic way. So BBNs consider the two types of risk because of propagation effects also in an indirect sense that produce feed-back on information and on different aspects not necessary linked in a direct way. In fact Bayesian decision theory is concerned with making decisions using statistics which provide information regarding some of the uncertainties under consideration, linked as a net system [3].

This paper starts with an introduction on decision making in general, which is the domain of analysis of landscape management. Particular attention is given to the relation between preference function and policy making, underlining how it deals with consent construction as a process of an informative flow and communication. Then the integrated model of landscape is presented as decision support system structured as a Bayesian Belief Network (BBN).

The description of model construction points out the aspects that permit the connection between the risks analysis and the integrated landscape management model, with attention to the participation of stakeholders. Finally the specific case of Diamantina landscape is discussed, concerning the network built to control the development of new settlements in that area, protected by UNESCO.

2 The decision making: reality and representation

The European Landscape Convention, signed in Florence in 2000, underlines the need for innovation in territory management, supporting new procedures for participation that take into account new approaches to decisions in the public field. Policy makers have to promote local development not only at an administrative level, but as active regulation of landscape as well, as required by their public role [4]. It's necessary, indeed, to organize decisional processes that guarantee efficacy of public policies and answer to satisfactory rationality standards. In order to point out the consequences of a collective choice, policy maker must dispose of knowledge in the field of intervention, defined "applied knowledge". This kind of knowledge is not a generic one, as "classes of possible actions", but it finds its character in precise spatial/temporal coordinates (place and context at present).

In particular, it's important to underline that two different patterns exist, one where applied knowledge forms itself (landscape as system), and the one where the choice takes form (work pattern of the policy maker). Such a separation between these two semantic fields constitutes the structural problem of rational policy formulation, with reflections in planning.

Furthermore, the applied knowledge is constructed through a global process of learning where policy makers, stakeholders and expertise have to take part [6]. It therefore becomes of fundamental importance that the procedure with which they acquire knowledge and contents of decisions, be adequately constructed paying attention and structuring the contributions of all the parts in cause.

With the model of integrated landscape management the authors try to structure a collective exploration process of applied knowledge, which is formed by communicating and sharing single points of view on landscape. This process allows a systematic comparison and a mutual control of the consistency and the significance of the generated knowledge. Contents and definition level of

landscape transformations found substance and consistency on how much more they will bear from the convergence between expertise, local actors and common sense.

3 Integrated model of landscape

3.1 Decision support system: the Bayesian Belief Networks (BBNs)

A Bayesian belief network (BBN), also called a belief network, is a type of decision support system based on a probability theory which implements Bayes' rule of probability. This rule mathematically shows how existing beliefs can be modified with the input of new evidence [7].

BBNs organize the bodies of knowledge in any given area by mapping out cause-and-effect relationships among key variables and encoding them with numbers that represent the extent to which one variable is likely to affect another. Briefly, a BBN is a series of nodes representing states in nature and the casual dependencies among them. The probabilities representing those linkages can be developed empirically or through expert judgment. A distinct advantage of this approach is that BBNs do not have to incorporate the complete mechanistic detail of more process-based models. Uncertainty about some indirect impacts or limited information is reflected in the vector of conditional probabilities for linkages that are defined [3].

BBNs have become a highly successful technique in medical diagnostic systems, analysis, artificial intelligence, and decision-making in real-world domains. They have been applied for many years in practice in a variety of fields, including engineering and science [8] [9], but always for specific problems. BBNs have gained a reputation of being powerful techniques for modeling complex problems involving uncertain knowledge and uncertain impacts of causes. So the authors applied them in landscape management which implies the interaction between various domains. The innovative experimentation permits to control different aspects and activities of the territory, as demography and tourism, settlements, architectural assets, mobility and infrastructures, the hydraulic aspect, the environmental and agriculture, considering the influences between them in a dynamic way.

3.2 Model construction

The integrated model is a tool that guarantees dialogue between institutional levels and for local involvement. Hence, the model must describe the territory and its transformation dynamics, with particular attention to the possibility to simulating scenarios and previewing impacts for verifying policies adopted and to be adopted.

A model is an analogical representation of a real phenomenon, finalized for a very precise scope, and defined to a determined level of abstraction [2]. The representation supplied from the model describes only relevant characteristics of the phenomenon identified through a preliminary analysis of importance. The modeling phases of each transformation are listed below:

- 1- Identification of the meaningful transformation of landscape;
- 2- To point out physical and cultural models regarding the local and logical context of it;
- 3- Identification of strategic parameters that quantify the physical-structural entity of the transformation, like entities of control, chosen by a precise participation procedure (the protocol for the construction of the model which regulates stakeholders' involvement [9]).
- 4- Identification of stakeholders who take part in the landscape transformation process (for example, institutions, public agencies, single enterprises or citizens, groups of interest).

The integrated model for landscape management uses Bayesian Belief Networks to organize the collected contents. The Bayesian model, thanks to its structure of semantic nodes, implements in a probabilistic way data and expressed information, interests and the know-how from the actors. In particular, the dynamics of the landscape transformation are represented by state variables, technical

variables and by strategic parameters referred to important physical models. The net, through its structure, ties variables by their direct implications. The non-determinist nature of the model allows connections between variables of different domains in the same network.

For each transformation a minimum-net is constructed, and these are linked to one another through ties between the single variables. The models are therefore structured in a global one representing all meaningful dynamics of landscape in a determined moment t (figure1). In fact each white rectangle contains a network that represents a transformation process of landscape. Networks are linked together by shared nodes of different dynamics represented. The influences between the nodes in the model are tabulated in a network matrix control.

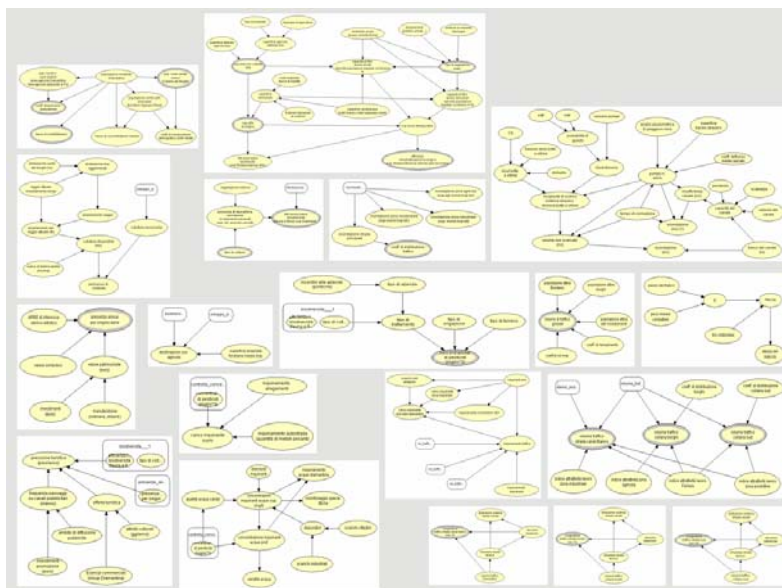


figure 1: Bayesian Belief Network of Diamantina Landscape

The model construction procedure (the stakeholder's protocol) is used to manage and define the contents of the formal and informal mandate that the actors have, and to analyze them from the point of view of the behavior or non-behavior (dynamic relational), due to normative implementation and to "ties" to the role of the stakeholders.

Through the protocol, the molders of the net acquire data and knowledge through an iterative and interactive process. Information collected from the local actors is mediated with expert knowledge.

The protocol is made of three levels (divided in 7 steps):

- 1- Construction of BBNs with stake holder's involvement (Steps 1 – 3): analyses of the context; identification of the factors, sets in action and pointers; construction of an integrated pilot model;
- 2- Quantitative BBN construction: data collection, definition of states, construction of probabilistic model (step 4-6);
- 3- Collection of feedback from stakeholders (step 7).

Every phase is managed directly from the molders of the nets who identify the participation and the encounter moments. The shape that the comparison can assume varies in function of the different contributions that the molder has to interpret and to record in the model through the links and variables. In fact, every meeting is set up on a specific topic (technical variables, strategic parameters, nodes, and links) as a numerical quantification of landscape property.

3.3 The analysis of the risk-landscape and the integrated model of management of territory

The aim of the risk analysis in landscape management consists in the protection and the valorization of the territory's identities and resources, for the safekeeping and reinforcement of its cultural, historical, environmental and archaeological inheritance.

Risk prevention in planning previews the programming and performance of actions in order to reduce possible danger factors. It's also important to organize the monitoring of the landscape real estate, in order to acquire the knowledge level needed to adapt actions and participation to it.

In the case of risk-landscape, vulnerability regards the patrimony to safeguard. In this way, the level of danger is defined by phenomena which produces the risk and which potentially invests the territory containing the assets. But the danger level also contemplates all extrinsic elements that deal with physical, environmental and social and human variables that in some way contribute to the manifestation of the degradation process. In this optic, dangerousness is evaluated on the local alteration tendency or on the possible compromising of the physical/functional characters of the single contexts.

From the model construction procedure, it is evident that in such a dynamic organization of data and information structuring the model, risk is considered in probabilistic terms - for which the likelihood of a negative event is not considered as present/not-present, but as the chance that whatever negative event -not *a priori*- can overthrow the acceptable threshold of the reference parameter value representing it. That it, it can provoke influences that lead to danger situations in others parts of the system even to those not directly connected to it. The network perceives risk not as an exception regarding daily dynamics, but as a probable variable state with respect to all the possible ones, highlighted from scenarios. In fact, models are used to simulate possible future scenarios highlighting situations which could be discussed during the policy's formation.

The simulation could be carried out in two ways. In the "Top-Down" simulation, it is possible to attribute probability values to the decisional variables, obtaining information regarding the strategic parameters. The aim is to verify the effects of a policy or an action applied to the system, which will be modified simulating the produced effects, by the propagation of the influences of the choices hypnotized. On the contrary, with the "Bottom-Up" simulation the molders assume values of probability on the strategic parameters and the variable states are checked, that is to settle the likelihood of performances that policy makers would the system to have and it is necessary then to discuss the different policies which could provoke, with greater or smaller probability, such effects.

The innovative aspect of this research is that it is possible to make actions operative in the model changing parameters, and to discuss the influences of other problem aspects that may generate and qualify it. The variation of some nodes active a revision of the BBNs probability values in general, by a multi-direction mechanism all around the system, revisited and recording changes to a new equilibrium.

Through the Top-Down or Bottom-Up analysis, is possible to inquire on dynamics that could create unacceptable situations for the system. The acceptable thresholds for each single variable therefore becomes important because it can provoke danger, that is, a risk situation. Such intervals are established in the participative process by the actors and the stakeholders according to the protocol. This procedure also acquires an educational character - learning actors' responsibility, in terms of action protagonists but, also in terms of shared regulation and control on tolerable limits. It is therefore fundamental to understand the involvement of the local actors, considering the level of risk perception, controlling and establishing acceptable thresholds as reference.

The comprehension of the risk dynamic amplitude has to be analyzed at the same of construction level as the landscape model, whose simulations include risk situation as "high probability of taking place" situations that shatter the shared threshold levels or as propagation of the influences that emerge as possible crisis situations, in apparently innocent areas, physically and semantically far from the

primary event. Moreover, through the net it is possible to make models of dangerous events in order to analyze the indirect influences that they logically have on the system.

The model dynamically develops and manages the location of the danger factors, through the simulation of scenarios, the verification of the parameters and of the influences, through the model of risks events, whose consequences influence the landscape model. BBNs are useful as model of risk assessment, because they describe cause/effect relationship between risk factor-base and landscape peculiarities, giving a probabilistic quantitative definition of risk functions thanks to Bayesian theory.

The way the model is constructed, promotes the participated analysis of factor-base of risk with an integration of the influences and of different points of view, that enter in different field policies and that mould possible strategies of protection. Another potentiality of the model is the possibility to be connected with GIS system for the automatic acquisition of the values of the variables.

With respect to the classical models of simulation or superimposition of effects, the BBNs as representation of risk, offer greater possibilities of employment, because of the ability to be calculated in direct sense (supplied values of the decisional variable it obtains the objective-variable values), and in inverse sense (supplied the objective-variable values it obtains the probable values of decisional variable that concurs to obtain such object). It promotes exactly a simulative employment in direction of a classic appraisal of composition of influences of the evolutionary political to which the landscape is subordinate, whose particular usefulness resides in showing common risks and secondary effects that it develops. But the managerial employment of BBNs consist in the identification of co-ordinate actions that points out combinations of undesired effects as support in the discussion of sector policy and strategies of protection.

3.4 The case study: Diamantina landscape

The integrated landscape management methodology is investigated in a case study in the Diamantina territory near Ferrara (Italy), declared 'protected landscape' by UNESCO in 1995.

The network is constructed focusing on innovative actions for precautionary landscape protection against risks on the holistic habitats protected by UNESCO, characterized by the presence of the Po River, with a great network of water channels and hydraulic engineering throughout the territory. Its morphologic conformation is also important, characterized by a 10 km large central depression, as the result of the Estes' drainage in the XV century, which still marks the Diamantina landscape in a coherent way even in the agricultural pattern and the property division. The spatial organization of the villages around the borders of the depression, the village "necklace", underline the "basin" perception due to the morphologic characteristics of the zone. The distribution in "rosary beads" is therefore an integrate part of the landscape unit, whose alteration would lead to an irremediable modification of the Diamantina. As example, this paper is focalized on the main topic of the settling system of the villages that encircles the zone of the Diamantina. Its peculiar organization in rosary beads as landscape border and balcony could be cancelled by an uncontrolled building development along the main arteries, process that would provoke the welding of the city centers, towards an indistinct inhabited continuum along the road's ridge. Moreover, the problem would be twofold: the welding of the villages would also compromise the system of the ecological corridors that put in relation the agricultural zone with the bank of Po River. The BBN has to describe and to control this process of building development and its implications.

The model of building development is structured in this way (figure 2): the starting nodes are the distance between two consecutive centers, the radius of each village, and the distance between the borders of the two villages, as the agricultural space between them. The output node is the ring of available surface that could be used to build new houses, if the distance becomes too small; the other node's "radius increase" will mark as proximal to zero the likelihood of the settlement's expansion. This event produces a cascade effect on the surface available, the strategic parameter of the net, on which the policy regarding soil destination is made. In fact, the "available surface" is tied also to its

use. This node is important because it takes in consideration not only the quantitative aspect, but also the qualitative one.

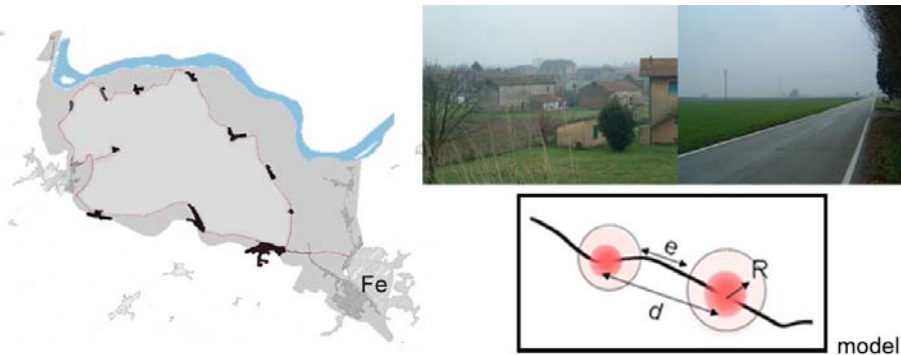


figure 2: necklace of Villages of Diamantina landscape (plan of the area, images, and model)

Furthermore, the “surface available” node is connected to the “need surface” node that records the effective requirements of the population in regards to demographic development, modeled in another network. These two nodes join into the "license to build" node that point out the possibility of new settlements balancing the inhabitants’ needs and the sustainability of them with respect of landscape perception.

Considering the compact configuration of each village, when the distance between them diminishes to 800m (valued establish by a participative procedure, the stakeholder protocol), the expansion possibility comes less, canceling the available surface for new settlements and limiting the building permits. This is how top-down and bottom-up scenarios are created and evaluated (figure 3).

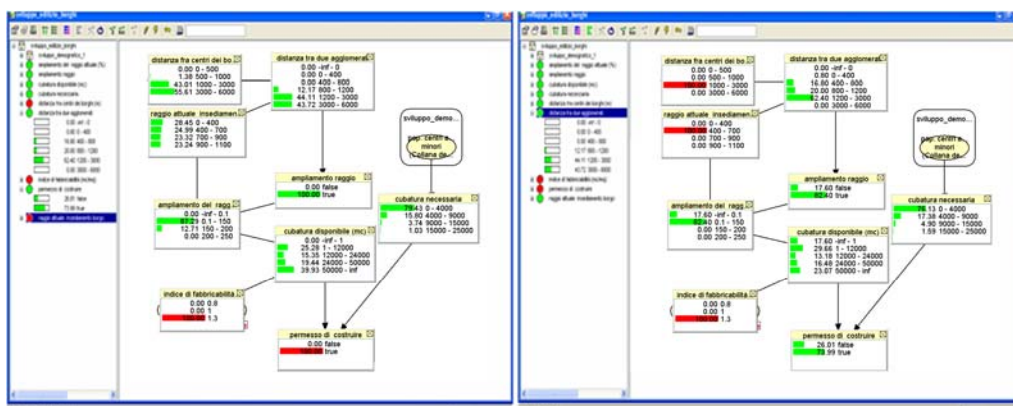


Figure 3: case study network: tables of probability of Top-Down and Bottom-Up simulations elaborated with Hugin software

In the first case, the radius amplitude parameters of the new settlement (with respect to a policy that be enacted), and the distance between two villages are established, the villages choices are taken into consideration. Then it’s possible to assign a value to the index of suitability of building, according to the policy that has to be evaluated. By using the simulation, the model visualizes as output the percentage of building site around the village analyzed, referred to the scenario modeled by Bayesian network. Therefore, in the innovative approach to bottom-up scenario, a value probability is assigned to the strategic parameter and it’s possible to observe what happens to the parameters of the other nodes. For example, it’s possible to verify the building index and the occupied surface sufficiently to obtain a final situation in which the policy maker consents a private person the permission to build with a high probability elevated soil occupation. In this case, policy maker can verify the policy’s social impact and its impact on the landscape which must be protected.

4 Conclusions

The authors have constructed a model simulating a participative procedure involving public authorities, the administration of Ferrara, and the local community. The experimentation took to the simulation of a number of scenarios which lead to important changes in the identity and characteristics of the UNESCO landscape under protection. The integrated landscape management tool tested permits to control different kinds of risks. In fact it's possible to control hydraulic risk, monitoring and operating on the strategic parameters that constitute the hydraulic network in the BBN. These strategic actions or phases were discussed with the stakeholders through the protocol of the network construction which allowed decision-makers to reach their own conclusions on the basis of their newly acquired understanding, achieved through the use of the scenario's simulation. The applications fostered the identification of a number of unforeseen implications which became evident as a result of the indirect correlation of different networks within the model. One example of this type of result can be seen in the relation between the development of the settlement network and the ecologic structuring of landscape network within the self-depuration capacity of the soil. Another example is the hydraulic risk and possible development of the viability network of the landscape monitoring the possibility to expand the existing principal arteries.

The applicative phase entailed the structured set up of participative events testifying the local involvement in the construction of a share landscape model.

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