A NEW APPROACH TO ENVIRONMENTAL IMPACT ASSESSMENT

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Abstract. A new approach to Environmental Impact Assessment (EIA), based on system dynamics concepts is presented in this paper. System dynamics models will however be useful in EIA only if people are able to develop "good" models. The conceptual basis for building an expert system designed to guide people in developing system dynamics models is introduced in this work. Such an expert system will have two main modules: a system dynamics component, which will include basic system dynamics concepts and heuristics; and a specific application component, which will consist of the main relations and rules governing a given environmental area. The system will also include an interface with a dynamic simulation language and with a decision aiding formulation.

INTRODUCTION

Environmental Impact Assessment (EIA) is an activity designed to identify the environmental impacts potentially produced by a proposed action; predict the magnitude of such impacts; evaluate their significance im terms of human well-being and select the most desirable alternative.

Since the introduction of the EIA process in the US in 1970, there has been a great effort in the development of systematic methodologies to perform the main tasks associated with EIA. These methodologies have, nevertheless had little practical use in EIA. Although several environmental impact identification methodologies are available, there is no process of obtainning a prediction of impact magnitude departing from the impacts identified in the first stage. Besides that, most identification methodologies do not provide a framework to define the causal relationships responsible for the triggering of environmental impacts.

System dynamics modelling can be a most useful tool in the identification and prediction stages of EIA, in the sense that one can build a model of the overall environmental system being affected and simulate alternative actions as different inputs to the model. The major problem with this approach lies in the large number of variables and relations that need to be included in such a model to make it minimally representative and useful. On the other hand, if the number of variables included in the model is too high, it will hardly run in a satisfactory way, and so one has to find an equilibrium between these two extreme points.

The development of an expert system designed to guide the user in the building of such models is described in this paper. This expert system will have two main components: a system dynamics module which contains the heuristic knowledge about model formulation and an application specific module which will describe the most important variables and interactions associated with a given type of action.

The first application of this system will be directed to the assessment of impacts related to water resources development projects.

THE ENVIRONMENTAL IMPACT ASSESSMENT PROCESS

An environmental impact can be defined as the net change in man's well-being and health induced by a given action or proposal. Human actions always produce changes in the current state of the environment (environmental effects), which in turn will have a benefical or adverse impact on man's well being.

In order to assess the environmental impacts of a given action one has, first of all, to obtain a description of the current state of the environment. Then, and based on that description, we need to obtain a forecast of the evolution of the environment through time with and without the proposed action. Comparing the two trajectories thus obtained, one can estimate the magnitude of the environmental impact (see Figure 1).

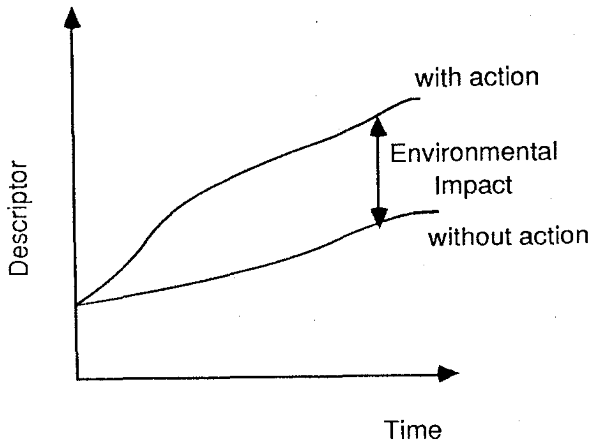

Figure 1. Impact magnitude measurement.

Apart from magnitude, impacts are also expressed in terms of their significance. Impact significance is a measure of how important is a given impact to society. While magnitude is an objective measure of the degree to which an environmental characteristic is affected by an action, the significance is a subjective measure of impact importance and therefore much harder to measure quantitatively.

As stated above, Environmental Impact Assessment is an activity designed to identify the environmental impacts of a proposed action; predict their magnitude; evaluate them in terms of their significance and select one alternative.

During the identification stage, one has to identify all the environmental areas potentially affected by the action. This implies not only the identification of the impacts caused directly by the action (primary impacts), but also the definition of those impacts resulting from the primary impacts (indirect or secondary impacts). Current identification methodologies include checklists, matrices, flow diagrams and overlay techniques. From these, the only ones which enable one to fully represent causal relationships and higher order impacts are the flow diagrams. These diagrams have however the drawback of becoming sometimes too large and cumbersome, as they do not have any variable selection mechanism. Matrices also enable one to identify causal relations, but only consider the direct relationships between action components and environmental characteristics.

In the prediction stage, one has to obtain an estimate of the magnitude of the impact over each of the impact variables identified in the first stage. This step is the least developed in terms of specific methodologies for EIA. Although there are some particular models which can be applied to predict changes in a given environmental area (e.g. air and water pollution dispersion models), most of the predictions are made based on expert judgement.

In the evaluation step one has to organize the information generated in the first two stages, in order to give to the decision maker all the data needed to select one alternative. In order to aggregate the information, one has first to adopt a common unit to measure the several impacts. If the unit adopted is a monetary one, then this evaluation is made applying cost-benefit analysis concepts. The major problem with this approach lies in the quantification of the economic value of the so-called intangibles. Another alternative consists of expressing the impacts in an environmental quality scale. Such transformation can be done using value fuinctions, for instance. Having expressed all the impacts in a common unit, one can obtain an environmental impact index as in the Battelle System (Dee et. al., 1973) by:

$$EI = \sum_{j=1}^{m} [(Vi)_1 - (Vi)_2]\, wi \qquad (1)$$

in which:

EI—environmental impact index

$(Vi)_1$—value in environmental quality units for environmental characteristic i with the action

$(Vi)_2$—value in environmental quality units for environmental characteristic i without the action

wi—weight assigned to environmental characteristic i

m—number of environmental characteristics.

The weights wi reflect the significance attributed to each environmental indicator. As they are rather subjective it is always very difficult to obtain a weighing system corresponding to the judgement of all the individuals affected or involved in a given action.

If all the impacts were aggregated in one unique index (economic or not), the selection of the best alternative is reduced to the choice of the alternative with the best value for the index. Most of the times it is preferable to consider the impacts grouped in broad environmental areas instead of aggregated in just one index. In these situations the selection of the most desirable alternative can be done using multicriteria decision methods.

EIA is a complex problem involving a large number of variables and relationships. A critical step during this process is the identification of the variables and causal relations to be included in the analysis. The prediction step is directly tied with the identification stage in the sense that one is measuring and confirming (or not) the impacts identified in the first step. The outcome of this identification and prediction stages is determinant for the remaining of the analysis and for the selection of the action to take.

PROPOSED APPROACH

System dynamics models could be a most useful tool in the impact identification and prediction steps in EIA. Having a model of the environmental areas potentially affected by a proposed action (or actions), one can simulate the different alternatives by changing the inicial conditions and rate variables (controls) in the model. Thus, one would obtain trajectories for the evolution of the levels (impact variables) under different strategies. A measure of the impact magnitude would then be obtained by comparing the reference mode behavior with such trajectories. New alternatives could be easily formulated by simply manipulating rate variables and initial conditions.

The main problem with this approach to EIA lies on the difficulties in model formulation arising from the large number of variables that one has to take into account simultaneously. Most people will tend to build very detailed models which will hardly run and be useful. This work is directed to the development of an expert system which will help people to build a system dynamics model. Such expert system will be mainly concerned with the selection of variables and development of causal relations between them, trying to avoid the inclusion of surperfluous variables in the model.

An expert system is a computer program designed to perform a task normally done by an expert, using heuristic knowledge captured from experts. Expert systems consist basically of a knowledge base, containing the fundamental knowledge in their domain and an inference mechanism including the reasoning rules which will act upon the knowledge base in order to solve a specific problem. These systems can perform several tasks including interpretation, diagnosis, monitoring, prediction, instruction, planning and design (Dym, 1985).

The system dynamics modelling expert system is a design expert system containning the rules needed to form a solution, that is the rules needed to build a dynamic model. Its knowledge base will consist basically of the properties of the desired solution and each solution attempt will be tested against such constraints. The expert system will have two main modules: a system dynamics module, which will contain the general principles and relevant heuristics in model design and an application specific module which will include the major relations existing among the components of a given environmental area. In its first application, the system will be used in the assessment of impacts related with water resources management plans. The system will also have an interface with a dynamic simulation language such as DYNAMO, STELLA or SLIN (see Camara et al, 1985) and with a decision aiding mechanism which will help the user in selecting the most desirable alternative.

System Dynamics Module

The system dynamics component of the expert system will result mainly from heuristic advice and guidance to the user and also from a set of tests designed to check the relations and equations introduced.

The expert guidance during the model design process will follow a general pattern of a question/answer dialogue. The first question that the system directs to the user is:

1. Select the most important levels.

Indicate the units used to measure each level.

For each of the indicated levels, the following questions are asked successively:

2. What flows in and out of the level?
   Indicate units to express these flows.

3. How are the inflows and outflows produced and controlled?
   (make sure to have some kind of primary control from the level in its outflows)

A first test on the dimensional consistency of the model is performed at this point by verifying if the rates that flow into and out of each level are expressed in the same units of the level divided by time.

If the model is dimensionally balanced, a first version of the causal diagram is presented to the user (if not, the user is asked to correct the wrong entries). This model can be shown simply as an adjacency matrix (Cristofides, 1985) showing the relations just entered. For each pair of variables (i,j), this matrix will have a value m(i,j), which will be equal to +1, -1 or 0, depending on the nature of the relation existing between them. If i depends on j and the polarity of the relationship is positive, then m(i,j)=+1; if the polarity is negative then m(i,j)=-1; if i does not depend on j, then m(i,j)=0. If one has a computer with graphical capabilities, then a first draft of the system dynamics diagram can be shown to the user. The user in then asked to check the model.

1. Check the boundary of your model.
   Do you think that you have included all the relevant variables?

2. Where do your inflows come from and where do your outflows go to?
   Do you want to replace any of your "clouds" by a level variable?

Once the user is satisfied with the diagram just developed, he is guided into the equation formulation process.

For each variable the user is reminded of all the other variables that it depends on.

1. Now try to formulate rate and auxiliary variables equations.

2. Remember that your relations can be defined as mathematical equations, as graphical functions or as logical relations (this last type of formulation is only used if the model is to be run using SLIN).

3. Test the robustness of the relations just defined.
   How do they behave under extreme conditions? (Questions like: what if variable X is zero? are made in this stage)

The dimensional balance of all the relations entered is verified now and if there are no inconsistencies, the final version of the model is given to the user or passed to the simulation language interface.

Environmental Impact Module

The general problem in EIA is to determine the results of the interaction of two sets: the environment set and an action set. Having defined the properties that enable one to fully describe the environment and the action, the EIA problem consists of defining the nature of the interaction between the two sets. However, these interactions (environmental effects) are only significant in terms of EIA, if they originate changes in man's well-being, and so one has to consider another type of relationship: the connection between interaction variables and impact variables. A model of the interactions "environment"— "action"— "impact" is presented in Figure 2.

The arcs connecting the elements of the different sets can be weighed according to a significance degree assigned to that relation. These weights can then be used to select the most important paths, so that the intervening variables should be preferably included in the system dynamics model.

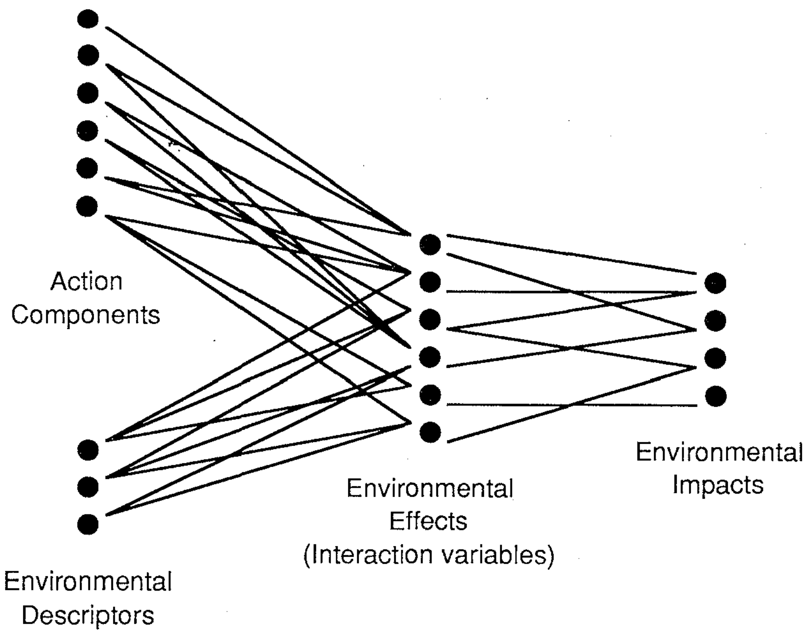

Figure 2. Structural model of Environmental Impact Assessment.

This structural model is shown to the user during the model design process whenever he needs. New variables and arcs can be added to this model if new relations are discovered during the model formulation and run.

To illustrate these concepts, let us examine a typical water resources management problem (taken from Camara, 1982): the impacts of municipal wastewaters upon a stream ecosystem. A structural model for such problem is shown in Figure 3.

The impacts of wastewater [xi] on a receiving stream result from alterations in the human use of that stream. These alterations are the result of the interaction between [xi] and the stream ecosystem. Typically, it is assumed that this interaction is produced at a point "a" of the stream and the uses in consideration are located from "a" to some point "b", located at a short distance downstream from "a".

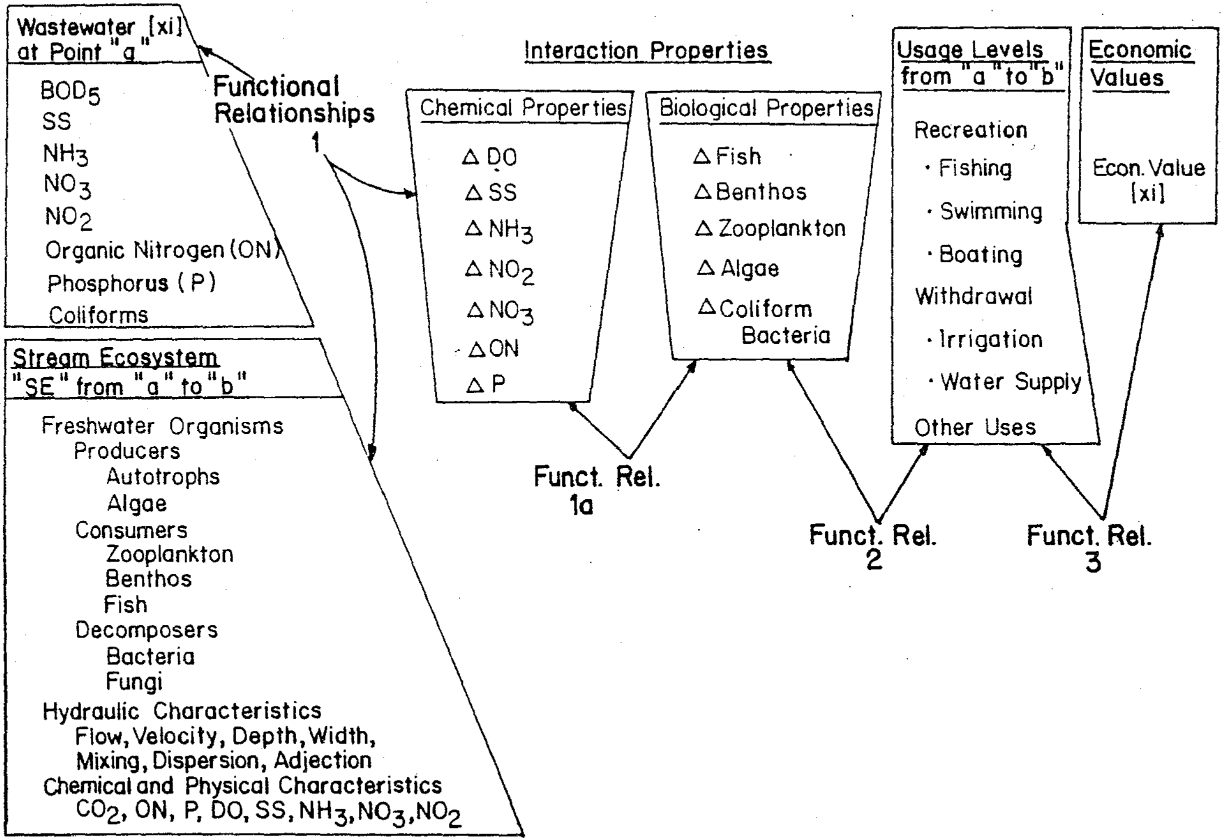

Figure 3. Structural Model to Assess the Impacts of Municipal Sewage upon a Stream Ecossystem

The estimation of those impacts, therefore, starts with the study of the interaction of two entities: the wastewater [xi] and the stream ecosystem "se". The analysis of this interaction begins by identifying the elements of [xi] and "se" between "a" and "b". The knowledge of those elements allows one to define the properties of the interaction that can be visualized as the result of the capacity of assimilation of "se" to [xi]. From the point of view of society, the knowledge of these interaction variables is only relevant if the stream is used by man. The magnitude of these uses is, in turn, functionally related to the valuations assumed by the properties of the interaction between [xi] and "se". Finally, that magnitude is reflected upon the economic value of the stream when receiving a pollution vector [xi].

SUMMARY AND CONCLUSIONS

A new approach to environmental impact assessment, based on system dynamics concepts was presented. In order to be useful in EIA, such models need to represent the environmental system being affected by a proposed action, taking into account all the relevant variables without becoming too large.

System dynamics modelling is a task performed mainly through the application of "rules of thumb" and knowledge accumulated from experience. The development of an expert system designed to guide the user in the development of system dynamics models was discussed. This system will consist basically of a set of system dynamics heuristics and a relational model of the environmental system and actions considered in a given EIA problem. The system will have an interface with a dynamic simulation language to enable the use of the developed model in the prediction stage of EIA.

This system is still in an early stage and there is a lot of work to be done in the development of its inference rules and knowledge base. Nevertheless the authors think that such a system, once made into an operational tool, can be very useful to those who intend to use system dynamics models, without having the knowledge and experience of an expert.

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