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A SATELLITE DESIGN FOR INTEGRATED

REGIONAL ENVIRONMENTAL MODELLING

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A SATELLITE DESIGN FOR INTEGRATED REGIONAL ENVIRONMENTAL MODELLING

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Contents

1. INTRODUCTION

Methodologies for analyzing multidisciplinary phenomena in an integrated or at least coherent way are increasingly becoming necessary because of the rise in complexity of (conflicted) planning and choice problems in our society. Especially in regional economic and environmental policy making many conflicting issues have come about in recent years, as is for example witnessed by environmental impacts of acid rain in natural parks. Also many other cases (fishery, agriculture, e.g) demonstrate the need of a rigorous systematic approach to current planning problems.

In the context of the paper, the structure of a regional economic model linked to an integrated environmental model will be discussed. We will make use of a systems theoretic approach to analyze the complex relationships in a spatial environmental economic system at a regional level.

An integrated environmental model (IEM) consists of a set of different modules corresponding to a number of interdependent disciplines. It is taken for granted that a complex reality can be projected as a multidisciplinary system which is modeled through relevant modules.

We will distinguish two model approaches in the paper, viz. a horizontal and a vertical model approach. They will be illustrated by recently operationalized models. The distinction between a horizontal model approach and a vertical model approach indicates that the relationship between variables from different disciplines can be analyzed in different ways. The aim of the paper is to design a mixture of the horizontal and vertical model structure, called a satellite model structure. In both the conceptual and the operational version of the satellite structure, a purely regional economic module here makes up the central part of the satellite model, as this is regarded as a key-mechanism in the environmental economic problems discussed in the paper. Special emphasis will be given to interdisciplinary and intradisciplinary relationships as well as to methodological problems inherent in the integration of mono-disciplinary modules. Four major methodological problems will be discussed in the paper, viz.:

1. The spatial aspect. This problem is caused by differences in spatial aggregation and scales in different modules. For example, various statistical methods have been developed to represent spatial patterns in ecology and recreation. A specific solution to this spatial problem, suggested in the literature, will briefly be discussed in section 3.1.
2. The precision of information regarding the model representation, for instance, binary, qualitative or quantitative information on the model structure. A number of graph theoretical tools that are available to ana-

lyze a model structure with low levels of information is discussed in section 3.2.

3. The level of measurement of variables, measured for instance, at either a nominal, an ordinal or a cardinal scale. The levels of measurement of variables differ because they refer to different disciplines. A broad family of linear models, called Generalized Linear Models (GLM), is discussed in the paper in section 3.3 to deal with these different types of information.
4. The temporal aspect, especially the different time horizons (temporal coverage) and temporal resolution for the modules.

Finally, the above mentioned methodological notions will be illustrated in section 4 on the basis of an empirical application to an integrated land use planning model in the Netherlands.

2. CONCEPTS OF AN INTEGRATED ENVIRONMENTAL MODEL

2.1 Introduction

An IEM is assumed to consist of modules which are based on specific disciplines (demography, ecology, land use, recreation, e.g.). Such modules are linked to each other. We will distinguish between interrelationships and intrarelationships. An intrarelationship denotes (the direction of) the impact between variables within the same module, while (the direction of) the impact of variables from different modules is represented by interrelationships.

An example of an intrarelationship within a demographic module is the population size which is influenced by the level of migration, whereas the recreation size causing phosphate concentration in water (eutrophication) is indicated by means of an interrelationship (links between modules).

A coherent and systematic approach to dealing with the association between modules is necessary. A useful tool to analyze the structure of strongly interdependent component is systems analysis or system theory (see also Bennett and Chorley, 1978; Caswell et al., 1972). A system is characterized in general terms by three components, viz. an input (say x) and an output (say y), linked to each other by means of an operator (or transferfunction), like $y=f(x)$. The transfer function can be linear or non-linear, static or dynamic, stochastic or deterministic in nature.

A system is defined here as a set of components (also called modules in the modelling phase) which are characterized and determined by relationships. The relationships are subdivided into the mentioned intra- and interrelationships and are determined by a (statistical) specified hypothesis or a priori information. A system with modules has to be seen as an entity because a partition into independent modules is not permitted, or "the behavior of the "whole" system is usually something very much more than the sum of the parts" (see also Wilson, 1981; p. 3).

We will distinguish between two model approaches dealing with integrated modelling, viz.:

1. A horizontal model approach. All relevant disciplines have an equal contribution in the phase of model development and model operationalization, so that the system is determined by interactions between monodisciplinary modules (see also section 2.2).

2. A vertical model approach. This model design makes use of an hierarchy of disciplines one (or more) of them being superior to all others. The vertical model approach places special emphasis on the relationship between the dominant module and the other modules, while other relationships are receiving less attention (see also section 2.3.).

A case study example of both approaches to link economic and environmental aspects will also be presented in this paper.

2.2 A Horizontal Model Approach

The interactions between monodisciplinary modules are characteristic in a horizontal model approach, so that this way of model specification and model operationalization is closely related to monodisciplinary research, neglecting methodological problems inherent to interdisciplinary model development. The links between economy and the environment in a horizontal model approach can be interpreted as interactions between monodisciplinary modules. A regional model with mutual dependence between the modules in such a model framework has been developed by Duckstein et al. (1980, 1982), while an analytical framework has been developed for phosphorus loadings reduction in a lake, with the lake Balaton area in Hungary as a case study example. The mutual dependence between economy and natural environment is represented by agricultural activities and phosphorus loadings reduction successively. Phosphorus loadings in water increase because of the use of commercial and natural fertilizers in agriculture. The economic and environmental goals (increase of agricultural benefits, in monetary terms, and reduction of phosphorus loadings, in terms of percentages) are conflicting to each other. A trade-off relationship between such variables is represented in figure 1.

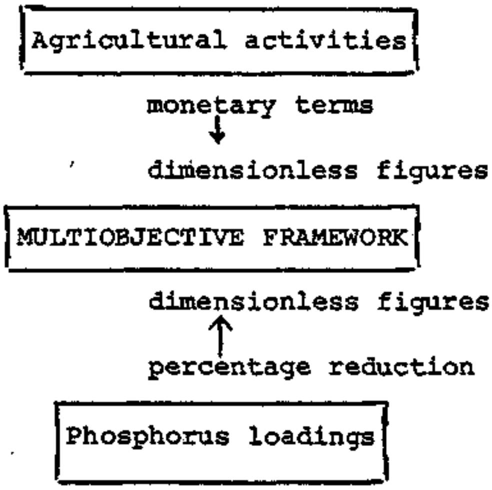

Figure 1. Trade-off relationship between agricultural activities and phosphorus loadings.

The two variables are related to each other in a multiobjective framework, after a transformation into dimensionless figures. No distinction between the variables has been made, because different units of measurement were transformed into dimensionless figures, which was the characteristic of the so-called horizontal model approach.

2.3 <u>A Vertical Model Approach</u>

The hierarchy of modules in a vertical model approach denotes that special emphasis is given to the relationships between the dominant module and the other modules, while the other interrelationships are assumed to be of only minor importance. A vertical model approach would be relevant in empirical applications if the level of one factor becomes the input for all other factors, while the interrelationships between the other factors are neglected in the analysis.
The hierarchy of modules within a vertical framework will be illustrated by a policy analysis of watermanagement for the Netherlands (or, shortly PAWN-study). See also the summary report of this study, Goeller et al., 1983. The consequences of alternative policies to manage the water resources of the Netherlands is managed by this study, and the model methodology which represents the links between the modules is given in Figure 2.

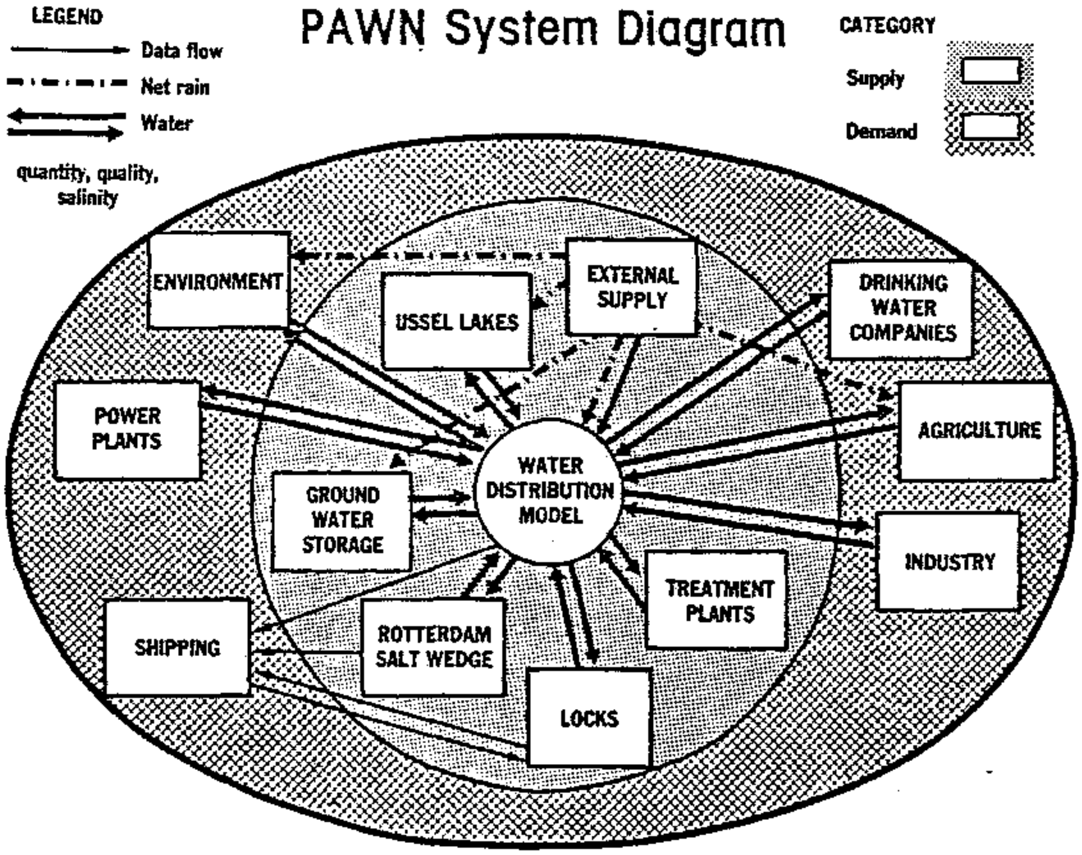

Figure 2. PAWN-system diagram
(Source: Goeller et al., 1983, p. 57).

The system diagram is subdivided into two main categories, viz. supply and demand in the different sectors. The core of the model approach is the water distribution module which simulates the distribution of water between the demand and supply categories from the different sectors. Only indirect links exist between the other modules. No direct links are modelized, for example, between agriculture and the environment.
The PAWN-study does not consist of one large model, but instead of that, it is based on a set of modules which are linked to the waterdistribution module. The emphasis on the waterdistribution module denotes the hierarchical nature of the model and is called for that reason a <u>vertical model</u>.
A main reason to select a vertical model approach instead of a horizontal model approach is the emphasis given to the direct relationship between the a priori selected dominant module and the other modules, the other relationships being treated of minor importance or neglected at all.
A vertical model approach is selected in empirical situations because "initial attempts to cover all topics in a similar degree of detail have proved to be overambituous, in terms of staff time and data availability, and more recently it has become almost standard practice to adopt an approach focusing upon selected topics with major implications for policy or for short-term investment programs" (Batey, 1984; p. 65).

2.4 A Satellite Model Design

We will now discuss the structure of a model design which is essentially a mixture of both a horizontal and a vertical model approach and makes use of a satellite principle. The interdisciplinary relationships and monodisciplinary relationships will be clearly distinguished in the satellite model approach described thereafter.

A regional economic model, developed through a satellite principle, can be summarized on the basis of the following characteristics:

a. There are individual modules which consist of variables related to each other by means of intra-module relationships.
b. Interrelationships exist at a more aggregate level between modules. Such interrelationships represent the level of integration of an interdisciplinary model.
c. All modules have economic dimensions while specifically the regional economic aspects of the economic dimensions are separately modelled in a regional-economic module which represents the core of the model structure. Demographic and ecological variables are, for example, interrelated with demand and supply of labour.

The satellite principle is used in two steps in the above mentioned characteristics:

1. Determination of the various main modules like, for example, demography, natural environment, social environment, etc. These modules are being analyzed in an integrated way which are in agreement with features (a) and (b) above.
2. Determination of the economic variables in the various individual modules: the regional components of the economic variables interact in a regional-economic module, which comply with characteristic (c) from above.

A main advantage of deal with such a satellite principle in an IEM is the possibility to distinguish between monodisciplinary and interdisciplinary relationships between variables, so that the satellite model approach becomes a mixture between a horizontal and a vertical model approach. A conceptual illustrative representation of an IEM which is the basis for our empirical application and which consists of 4 modules is represented in Figure 3. The modules are defined in the following way:

1 = demographic module
2 = artificial environment module
3 = natural environment module
4 = regional-economic module

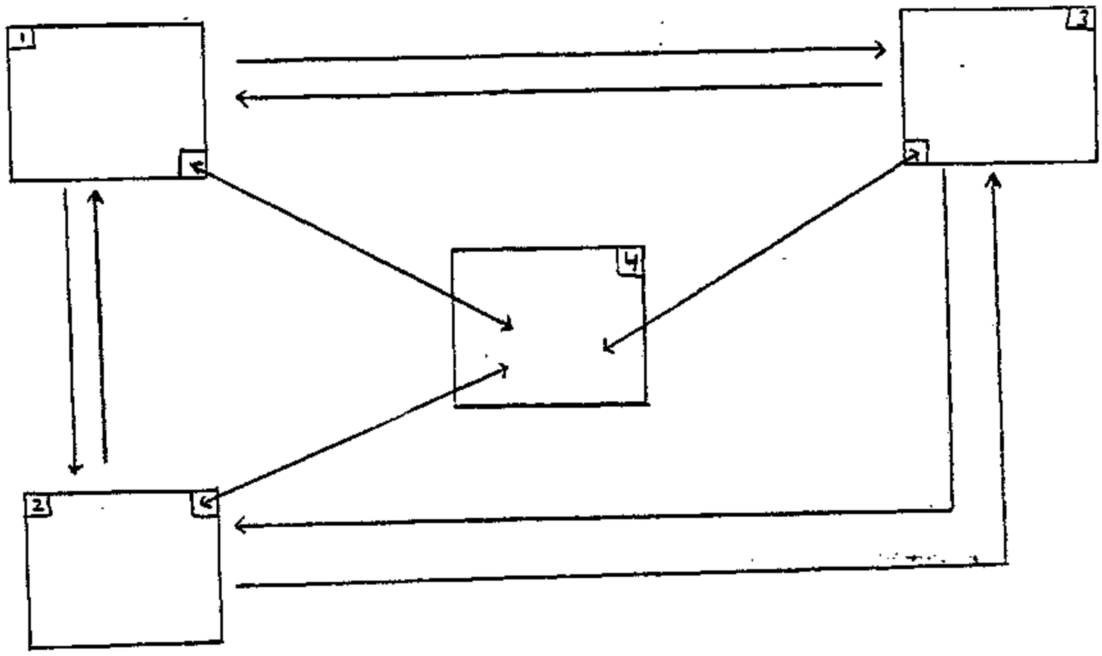

Figure 3: Satellite Structure of an Integrated Environmental Model

The conceptual representation of an IEM in Figure 1 shows that the modules 1, 2 and 3 contain input as well as output transfer functions to all other modules. The model specification denotes whether some transferfunction in Figure 1 is really part of a model.

Now we will discuss the satellite structure in Figure 3 in an empirical application, viz. a regional-economic model linked to an IEM in the Dutch regional area West-Noord-Brabant (see also Arntzen et al., 1981).

Here we will only make use of those parts of the IEM which are relevant in the present context to illustrate the satellite principle of an IEM in an empirical application.

A simple structural form of an IEM consists of the four modules mentioned above, every module being determined by one or more associate variables.

The demographic module consists of the following variables:

(1) Population size (classified by sex and age and represented via cohorts).
(2) Migration.

The regional-economic module consists of the following variable:

(3) Supply of and demand for labour.

The artificial environment module consists of the following variables:

(4) Demand for and supply of houses.
(5) Water use by households and firms.
(6) Size of recreation (classified according to recreation types and areas of origin/destination)

The natural environment module consists of the following variables:

(7) Phosphate concentration.

(8) Nitrate concentration.

(9) Level of nitrogen oxydes emissions (NO_x).

(10) Level of sulphur dioxyde emissions (SO_2).

These 10 variables have been selected because of their relevance in the specific empirical situation. The satellite structure of a regional-economic model linked to an IEM will now be represented in Figure 4.

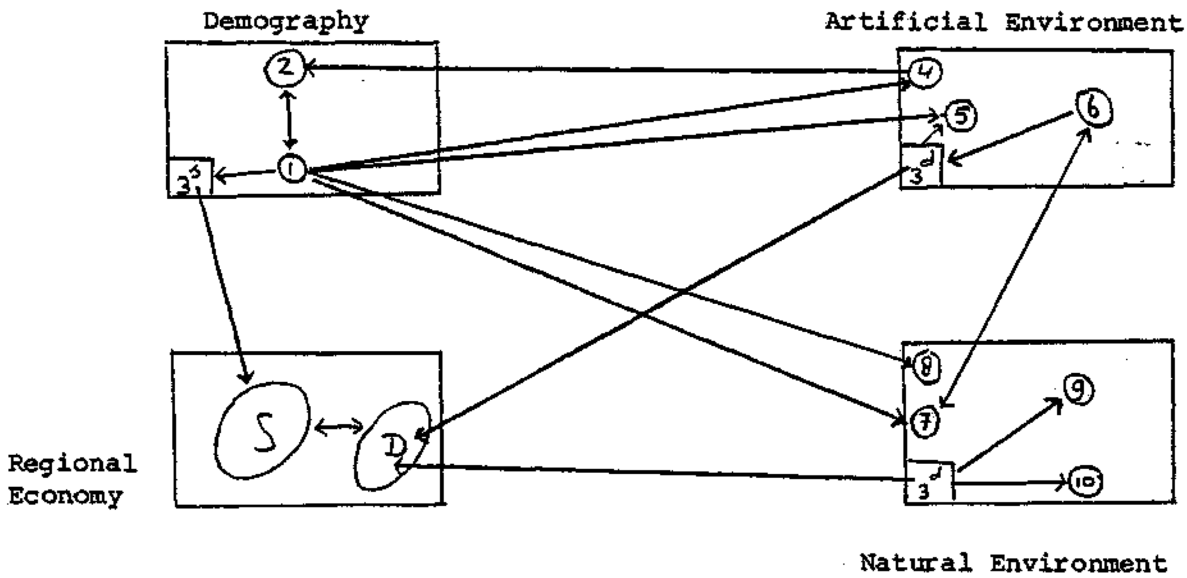

Figure 4: Satellite Structure of an Integrated Environmental Model.

The two phases in the satellite principle discussed above can be shown by means of Figure 4. We start with selecting the relevant variables from the modules: demography, artificial environment and natural environment as well as the intra-module relationships and inter-module relationships.

The second phase consists of the selection of the economic aspects from the separate modules, like supply of and demand for labour (variables 3a and 3d, respectively) while the regional components from such economic variables interact in a regional economic module. We showed above that the satellite principle is a mixture of a horizontal and a vertical model approach. The horizontal model approach is represented by the relationhips between the modules: demography, artificial environment and natural environment, and the relationships between the regional-economic module and the other modules represents a vertical model approach.

Thus far we have discussed the concept and a first example of a regional economic model linked to an IEM; all economic aspects are part of the sepa-

rate modules and the regional economic variables belong to a regional economic module, which is the core of the modelstructure.
A number of methodological problems related to the integration of mono-disciplinary modules is discussed in the next section.

3. METHODOLOGICAL PROBLEMS IN AN IEM

Four methodological problems, inherent to the integration of modules, are discussed in this section, viz.:

(1) Spatial aspect, viz. aggregation level and scale level.
(2) Structure of the relationships and different levels of information (viz. binary, qualitative, cardinal).
(3) Variables and different levels of measurement (e.g. nominal, ordinal, cardinal).
(4) Temporal aspect, viz. different time horizons (medium-term and long-term impacts).

These issues are discussed in sections 3.1 to 3.4 respectively (see also Brouwer et al., 1984a).

3.1. The Spatial Aggregation and Scale Level

The aim of the paper is to discuss the design of an integrated environmental model, described and quantified at a regional level. For that reason the spatial level and its consequence for model results is discussed in this section. The representation of spatial patterns plays a dominant role in, for example, recreation analysis and ecology.
In the early fifties a number of statisticians noted that model results with spatial analyses depend on the spatial units by means of which variables are measured (see also Kendall and Yule, 1950). The importance of the spatial units is well described by Kendall and Yule because they state: "Our relations will accordingly measure the relationship between the variates for the specified units chosen for the work. They have no absolute validity independently of these units, but are relative to them. They measure, as it were, not only the variations of the quantities under considerations, but the properties of the unit-mesh which we have imposed on the system in order to measure it." (Kendall and Yule, 1950, p. 312).
In subsequent years geographers and regional scientists also discussed the importance of the measurement unit of variables, subdivided into spatial aggregation level and spatial scale level and called the "modifiable areal

unit problem" (see also Openshaw and Taylor, 1979; 1981).
The scale level denotes the different modelling results when spatial data are defined into increasingly larger areal units. The scale level in spatial analysis can be compared with the micro-analysis versus macro-analysis in economics. The aggregation level deals with the wide range of alternative possibilities of partitioning an area into a fixed number of spatial units, viz. at a chosen scale level.
An application of the wide range of correlation coefficients depending on the different aggregation and scale levels can be found in Openshaw and Taylor (1979).
One might suggest to compute statistical measures like correlation coefficients at the individual level, meanwhile neglecting spatial effects of modelling results. For that reason Openshaw (1983) proposed to solve the problem of scale level and aggregation levels in a specific spatial way. He therefore suggested an algorithm to deal with the modifiable areal unit problem,which determines the aggregation level conditional to a chosen scale level (viz. the number of sub-regions) and a selected criterion function which will be optimized. An useful criterion function for computing correlation coefficients may be the optimization of the correlation between variables.
The aggregation problem is solved when a classification of subregions is determined by means of functional relations, determined by multiple relationships between regions while a number of attributes are a functional unit. In such a case the scale level still affects model results (see also Fischer, 1978). A homogenous region can be characterized by, for example, geographical, physical, environmental or economic factors emphasizing "human behavioral processes, such as perception, learning, attitude formation and decision making" (Gale and Golledge, 1982; p. 60). We can conclude from the above that the simultaneous choice of scale and aggregation levels are extremely relevant for areal parameters like, for example, density, pattern and average number of events per unit area. This has to be notified in the phase of operationalizing the concepts of an IEM.

3.2. Structure Analysis of an IEM

A structure representation of a simplified empirical situation has been given in figure 2 by means of a set of binary relationships. This indicates whether or not a certain variable has an impact on another variable. In such a case the direction of impacts is the only information available, and such information can be represented by zero/one value. Graph-theoretic methods are a useful tool to analyze the causal structure of such models (see als Roberts, 1978; Tinkler, 1977).

The analysis of the causal structure of an IEM is discussed in this section, with special emphasis on the different levels of measurement included in such models. The association between variables is analyzed when binary information is the only available information about the impacts (i.e. with information whether or not impacts exist between variables).

When the sign of the binary relationship (either positive or negative) is also known, indicating the qualitative direction of the impact of the one variable upon the other one, qualitative calculus (or the analysis of qualitative relations) can be applied to operationalize such models (see also Greenberg and Maybee, 1981). The relationships between variables are analyzed in a qualitative way, with information from the signs of the response variables obtained by prior knowledge about the structure parameters in a model. Only one aspect of qualitative calculus will be dealt with in this section, viz. sign-solvability analysis (see also Brouwer et al., 1984b).

Consider a model of the type Ay=b, with y a vector of endogenous variables, b a vector of constants and A a matrix with structure parameters. Both A and b contain only qualitative information.

Sign-solvability of a set of linear equations Ay=b becomes relevant when the model can be solved only in a qualitative way (viz. y expressed in terms of A and b) in case of unquantified and unestimated equations because of lack of (sufficiently reliable) data. The solution procedure of the reduced form equations consists of two steps, viz.:

- inversion of matrix A.
- computation of A^{-1} b.

Both steps need to have unique solutions in terms of their signs in order to be able to solve a linear model uniquely.

Sign-solvability denotes the identification of the sign of the changes of the endogenous variable (either positive, negative or zero) due to exogenous changes in the set of variables while the only information is the signs of the structure parameters. When the model structure is represented in terms of signed digraphs (directed graphs with signs either positive or negative), we obtain a visualization of the qualitative impacts between variables. Conditions for sign-solvability in terms of signed digraphs which are necessary as well as sufficient have been developed by Bassett et al., 1968.

The conditions of sign-solvability are rather severe; see also Brouwer et al., 1984b for a discussion of sign-solvability of the well-known economic model of the U.S.A. developed by Klein. For that reason in that paper sign-solvability of a set of linear equations is discussed if a mixture of qualitative and quantitative information about the structure parameters is available. A stepwise selection procedure is suggested to solve a set of equations in a qualitative way. This approach becomes meaningful when a qualitative model is not fully sign solvable (i.e. solvable in a unique way up to its sign), because then we need additional information (at an ordinal or cardinal measurement level) to obtain sign-solvable results. We may conclude from the above that qualitative calculus, especially sign-solvability, can be regarded as a method to solve either static or dynamic models with qualitative information about the impacts between variables. Sign-solvability is a major issue in integrated environmental modelling in case of non-metric information regarding parameters.

3.3. Variables Measured at Different Measurement Levels in an IEM

In the history of regional economic analysis the main focus has been on the analysis of variables measured at a cardinal metric (viz. on a ratio or interval scale). Regional economic modelling is like many modelling efforts in the social sciences, often confronted with information that is non-cardinal in nature (for instance, obtained from survey-designs, and measured at a categorical scale). For instance, surveys may contain categorical data classified in a dichotomous or a polytomous sense, such as: sex (male/female), recreation type (land recreation, water recreation, fishing). These variables can only be distinguished by their names or attributes and are measured on a nominal scale. Categorical data may be represented in contingency tables, with cross-classified variables as cell-entries (see also Bishop et al., 1975).

In this section we will describe a broad family of generalized linear models (or shortly GLMs), developed by the statisticians Nelder and Wedderburn (1972). The reason for the description in this section is the occurrence of a mixture of measurement levels of variables in integrated environmental modelling. Consider for example the recreational effects (classified into categories and measured at a nominal scale) due to changes in income levels (measured at a cardinal scale). The GLMs make a comparison between different types of linear models possible, because the GLMs are characterized by three aspects (see also Nelder, 1984):

(1) A response (or dependent) variable y is distributed independently, with mean μ and a variance-covariance structure for the response variables determined by the underlying probability distribution function.

(2) A linear relationship, say $E(y)=X\beta$, exists between μ and the set of explanatory (or stimulus) variables; X is a design matrix of explanatory

variables and β a vector of parameters to be estimated.

(3) A relationship is defined between y and its mean μ, viz. $\mu = f(y)$, where f is called a link-function.

The generalized linear models consist of a broad family of linear models, e.g. the classical ordinal least squares regression model, the analysis-of-variance (ANOVA) model, the logistic regression model and the log-linear model with contingency table analysis.

Different types of GLMs are obtained by varying either the distribution function of the response variable and/or the link function f. The normal regression model for cardinal data will be obtained, for example, if the observations are assumed to be normally distributed with mean μ and variance σ^2, based on a linear link-function. A computer package which is developed for dealing with GLMs is GLIM (Generalized Linear Interactive Modelling). A number of linear models can be obtained by options in the GLIM package (see also Table 1).

Linear Model	Error function	Link function
Linear regression	Normal	Identity
ANOVA (fixed effects)	Normal	Identity
ANOVA (random effects)	Gamma	Identity
Log-linear model	Poisson	Logarithmic
Logit regression	Binominal	Logit

Table 1: Different Types of GLMs (Source: O'Brien, 1983, p. 333).

Log-linear modelling with contingency tables is an exploratory methodological tool for analyzing the structure of sets of data decomposed into main effects and interaction effects. Maximum likelihood estimates of cell-elements and parameters are obtained from a log-linear model when based on a Poisson error function and a logarithmic link function. The variables are based on a discrete set of numbers which can be interpreted as a sample from a discrete probability distribution function, viz. the Poisson distribution.

Log-linear modelling analysis gives identical maximum likelihood estimates of cell-frequencies and parameters when the observations follow a Poisson, a multinominal or a product multinominal distribution function.

4. LINK BETWEEN SATELLITE STRUCTURE AND METHODOLOGICAL PROBLEMS: A DISCUSSION

In section 2 and section 3 we discussed the concept of an IEM based on a satellite principle as well as a number of methodological problems which are relevant in integrated modelling at a regional level. The link between these topics will now be discussed in this section. The relevance of the above mentioned methodological problems in an IEM is summarized in Table 2.

Methodological problems	Relevance in an IEM
1. Scale / aggregation level	- variables with a spatial dimension
2. Temporal dimension	- different time-horizons in multidisciplinary analysis (e.g., economy and environment)
3. Structure analysis with binary information	- lack of sufficient data - lack of reliable data - model interpretation with causality analysis and a minimum set of information
4. Model operationalization with different levels of measurement of variables	- exploratory analysis with survey data at a nominal scale - a coherent set of linear models of the GLM type - metric / non-metric data in modelling

Table 2: Relevance of the Methodological Problems in an IEM

A regional economic model linked to an IEM has been developed in concept in section 2 with the aid of a satellite principle. The link between all non-economic modules is determined in a first step by means of a specification of the interrelationships of the relevant modules (demography, artificial environment, natural environment, e.g.). The core of the model consists of a regional-economic module, because all economic aspects of the other modules are assumed to be part of the regional-economic module.

The first part of Table 2 mentioned the relevance of the spatial scale level and aggregation level for all variables with a spatial dimension. The interaction between variables can be determined at a certain scale and aggregation level. Regional modelling results depend on the scale and aggregation level. In view of the satellite principle, the regional economic module is regarded here as the core of the model structure and for that reason the definition of spatial objects must take part of the development of an IEM at a regional level.

The first part of Table 2 is relevant in an IEM because of the regional scale of the model, e.g. the regional economic module which consists of for example demand for and supply of labour or a recreation module which may consist of the spatial spread of different recreation categories. The temporal dimension is relevant in an IEM because of the different time-horizons of e.g. economic or environmental impacts which are analyzed in an integrated way.

The third part of Table 2 shows the relevance of structure analysis with binary information. When either theoretical knowledge about the specification of an IEM with a complex structure is scarce, and/or when necessary data are not reliable or not available at all, graph-theoretic methods and qualitative calculus are useful tools to analyze the association between variables or to solve a set of equations in a qualitative way. By means of such approaches the variables are not distinguished because of their specific characteristics: the signs (either positive or negative) of the structure parameters is the only information used. The lack of sufficient or reliable data would lead to scepticism with numerical quantified modelling results.

In addition, a number of exploratory and explanatory modelling analyses with observations measured at a cardinal or a nominal scale can be related to each other in terms of generalized linear models. The GLMs can be compared with each other because of the common statistical basic characteristics (see also section 3.3).

In the next section, an empirical application of these ideas to an integrated land use planning model in the Netherlands will be given.

5. EMPIRICAL APPLICATION OF AN IEM

The structure of an IEM which follows the satellite principle, with variables selected because of their relevance in the empirical illustration, has been represented in Figure 4.

The model structure, especially the association betweeen variables, can be quantified with the aid of graph-theoretical methods and Boolean algebra. A graph-theoretical analysis does not make use of the specific characteristics of the variables. A graph representation of Figure 4, with arrows denoting whether an impact between variables is considered, is given in Figure 5. The elements in this figure numbered 1 to 10 are interpreted in the same way as the variables from Figure 4.

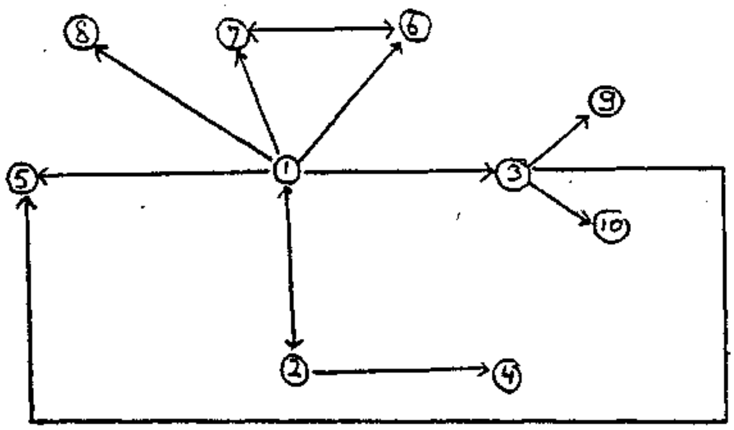

Figure 5: A graph representation of a model structure with directed graphs

A computer package, available at the Amsterdam computer centre, is GRADAP (Graph Definition and Analysis Package), with program input analogous to SPSS, is capable to deal with either directed or undirected graphs.
The so called adjacency matrix A consists of cell-entries 1 or 0, which depend on whether or not an impact between variables is assumed respectively. The outdegree and indegree give the number of outgoing and incoming impacts for some elements in a graph. A number of statistical measures for the graph in Figure 5 are summarized in Table 3.

	outdegree	indegree
minimum	0	1
maximum	7	2
mean	1.4	1.4
median	.5	1
variance	4.44	.24
spread	5.6	.6

Table 3: Statistical Measures of Outdegree and Indegree

Figure 3 shows that variable 3 has a direct impact on all variables except two, while variables 4, 5, 8, 9 and 10 do not have any impact on some other variables. This conclusion is in agreement with the wide spread pattern of the outdegree from Table 2. A zero outdegree of some point (which represents a variable) indicates that the level of the variable has no effect on the level of any other variable.
A graph representation of a model structure with directed graphs only makes use of zero- one information about the impacts between variables with special emphasis on the relationships themselves, neglecting the characteristics of the variables.

In the following we will discuss sign-solvability analysis which makes use of signed directed graphs (see also section 3.3), solving a simultaneous system of equations with a linear structure. Consider in this case a five equations system:

y_1 = population size

y_2 = migration

y_3 = supply of/demand for labour

y_4 = recreational size

y_5 = phosphate concentration

We selected one exogenous variable, viz. the supply of the number of houses (d), with model structure:

$y_1 = f_1\ (y_2, d)$ $\qquad$ $y_4 = f_4\ (y_1, y_5, d)$

$y_2 = f_2\ (y_1, y_3)$ $\qquad$ $y_5 = f_5\ (y_4)$

$y_3 = f_3\ (y_1, y_2, d)$

Figure 6 denotes the model structure with signed digraphs.

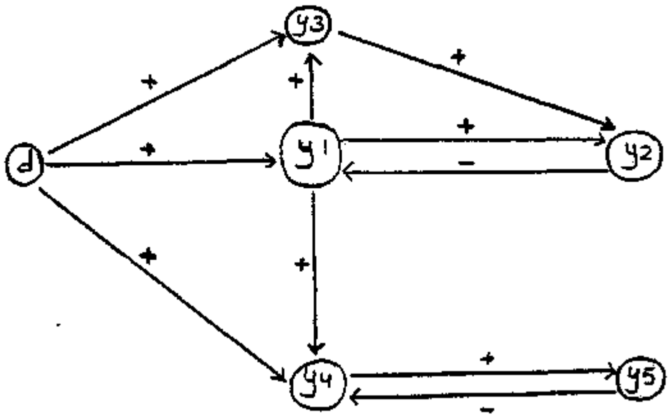

Figure 6: Model structure with signed digraphs

Variable y_3 is the regional economic variable which is related to the other dependent variables in the above mentioned way. The sign-solvability analysis denotes the sign of the changes in the dependent variables, either positive, negative of zero, due to exogenous changes in the set of variables. The qualitative linear system Ay=b is solved for y where Á is the matrix which contains the signs of the partial derivatives with respect to the dependent variables and b the sign vector of derivatives with respect to the exogenous variable whose impact is considered and y the unknown vector of impact multipliers.

The matrix representation of the set of equations then becomes:

$$\begin{bmatrix} 0 & - & + & + & 0 \\ + & 0 & 0 & 0 & 0 \\ 0 & + & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & + \\ 0 & 0 & 0 & - & 0 \end{bmatrix} . \begin{bmatrix} dy_1 \\ dy_2 \\ dy_3 \\ dy_4 \\ dy_5 \end{bmatrix} = \begin{bmatrix} + \\ 0 \\ + \\ + \\ 0 \end{bmatrix}$$

The matrix A can be partitioned into four sub-matrices, with one zero-matrix:

$$\begin{bmatrix} A_{11} & A_{12} \\ 0 & A_{22} \end{bmatrix} \begin{bmatrix} dx_1 \\ dx_2 \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \end{bmatrix}$$

with A_{11}, A_{12}, A_{22}, successively, a 3x3, a 3x2 and a 2x2 matrix. The solution becomes:

$$\begin{bmatrix} dy_4 \\ dy_5 \end{bmatrix} = \begin{bmatrix} 0 & - \\ + & 0 \end{bmatrix} \begin{bmatrix} + \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ + \end{bmatrix}$$

and

$$\begin{bmatrix} dy_1 \\ dy_2 \\ dy_3 \end{bmatrix} = \begin{bmatrix} 0 & + & 0 \\ 0 & 0 & + \\ + & 0 & + \end{bmatrix} \begin{bmatrix} + \\ 0 \\ + \end{bmatrix} = \begin{bmatrix} 0 \\ + \\ + \end{bmatrix}$$

$\rightarrow$

$$\begin{bmatrix} dy_1 \\ dy_2 \\ dy_3 \\ dy_4 \\ dy_5 \end{bmatrix} = \begin{bmatrix} 0 \\ + \\ + \\ 0 \\ + \end{bmatrix}$$

A positive change of the supply of houses will have a positive effect on variables y_2, y_3 and y_5, when considering the mentioned structure of equations. All signs of variables are full sign-solvable, because no elements of y are undetermined.

In section 3.1 we discussed the effects of aggregation level and scale level of variables related to a spatial dimension. This will be illustrated in this section for recreation levels in the Markizaat area, with four recreation types and four distance levels from the recreation area (see also Arntzen et al., 1981). The recreation levels in 1980 are given in Table 4.

distance category / recreation type	0-10 km	10-20 km	20-30 km	30-40 km	Total
1= amphibic recreation	1723	1203	2082	993	6001
2= extensive land recr.	595	815	629	1441	3480
3= sport fisheries	27	40	29	0	96
4= water sports	172	291	363	923	1749

Table 4: Recreation levels in Markizaat Area

At this aggregation level and scale level, the measure of correlation for the recreation types can be computed with the coefficient of Pearson for cardinal data. These results are given in Table 5.

	1	2	3	4
1	1.00	-.82	.44	-.62
2		1.00	-.83	.96
3			1.00	-.89
4				1.00

Table 5: Correlation coefficients of recreation types

In Table 6a and Table 6b we will distinguish between scale effects and aggregation effects successively.
Scale effects occur when the recreation levels are aggregated to less distance categories like, for example, 0-10, 10-20, 20-40 km from the Markizaat area. Such correlation coefficients are given in Table 6a. Aggregation effects of the recreation types are given in Table 6b.

	1	2	3	4
1	1.00	.92	-.57	.93
2			-.22	.99
3			1.00	-.26
4				1.00

Table 6a: Correlation coefficients of recreation types (scale effects)

	1	2	3	4
1	1.00	.89	.19	.87
2		1.00	.24	.99
3			1.00	.22
4				1.00

Table 6b: Correlation coefficients of recreation types (aggregation effects)

Scale effects can be shown when the correlation coefficients of Table 5 and Table 6a are compared with each other. Consider for example the correlation between recreation categories 1 and 2, which are equal to -.82 and .92 respectively. The reason of the great difference between the same recreation categories is the chosen scale level. The same conclusion of the aggregation effects can be drawn when the results of Table 5 and Table 6 are compared with each other.

CONCLUSION

The concept of a regional economic model linked to an IEM as well as four methodological problems in integrated environmental modelling have been discussed in this paper. The satellite design constitutes a useful distinction between a mono-disciplinary regional-economic module and the integrated pattern of relationships between all other relevant modules. The above mentioned methodological problems are especially relevant when we analyze the impacts between variables from different disciplines.

The scale effect and aggregation effect are relevant because an IEM is operationalized at a regional level with e.g. regional-economic variables, like employment and production, having a spatial dimension. The other methodological problems, viz. time dimension, structure analysis with binary information and the different levels of measurement of the variables, become relevant when the interrelationships between different modules are to be operationalized.

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