SERIE RESEARCHMEMORANDA

AN OPERATIONAL MULTI-COMPONENT
MULTI-ACTOR POLICY MODEL FOR
ECONOMIC-ENVIRONMENTAL SCENARIOS

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1. Introduction

Post-war advances in computer technology have favoured the introduction and use of computer-based decision and choice models in the area of both micro- and macro-economics. This trend has been favoured by two circumstances : (1) the enormous progress made in designing and implementing operational models based on advanced mathematical, statistical and econometric tools, and (2) the potential offered by modern computer software allowing the researcher to deal with complex and large-scale systems.

This development has exerted a deep-going impact on decision analysis. Decision analysis aims at judging a range of feasible options on the basis of a set of relevant evaluation criteria so as to eliminate less desirable options and to identify the most favourable alternative(s). In macro-economic decision analysis, however, the researcher is usually confronted with intriguing problems such as: a macro-economic system is usually displaying a multidimensional complexity, so that an integrated view is very hard to obtain; the system is influenced by multiple (formal and informal) actors with conflicting priorities and interests, so that an unambiguous macro-economic welfare criterion is lacking; there is a wide variety of diverse regions in a national system each of them interacting with the nation as a whole and with the other regions.

These considerations lead us to the specification of the following requirements for an integrated macro-economic model for decision analysis:

- The model should - in addition to (socio-)economic components - also include environmental and energy components so as to allow one to study the system at hand from an integrated viewpoint.
- The model should also incorporate the objectives set forth by (formal and informal)actors so as to do justice to the existence of diverging interests in society (leading to multiple objective analysis).

- The model should also encompass spatial dimensions in order to take account of the regional diversity of a complex national system.

These requirements imply a plea for an integrated multi-objective multi-regional model. This paper aims at presenting such a model for integrated economic-environmental-energy policy analysis in the Netherlands. Section 2 will describe some general methodological features of such a model. Next, in section 3 a plea will be made in favour of interactive decision analysis in order to provide a method for conflict resolution. Then in section 4, a conceptual version of a so-called Triple Layer Model will be presented, followed by a specification of an operational model in section 5.
Further details and empirical results will be discussed in sections 5 and 6, respectively.

2. Integrated Macro-economic Policy Models

A complete macro-economic policy model provides a stylized and consistent picture of (a part of) a complex reality. In general, economic, environmental and socio-political models may be regarded as images of the real world created by model-builders. Models used in policy analysis should be able to present the boundaries within which policy decisions are to be made, the tradeoffs inherent in choosing alternative solutions, the impacts of policy measures on a set of relevant policy targets, possibilities for a communication between experts (or planners) and decision-makers, and the sensitivity for changes in the spatial scale, the time horizon or the level of measurement of variables.
Such methodological conditions are hardly fulfilled in modeling practice, so that the determination and the judgement of the unique optimal state of the system is fraught with difficulties. Consequently, many conventional programming approaches have only a limited validity in the practice of policy analysis. That is also the reason why - instead of optimality analyses - impact analyses, effectiveness analyses, decision support analyses and strategic decision analyses have received increasing attention in recent years. In such analyses, much emphasis is placed on the effects of policy objectives and policy instruments, the role of conflict management and the meaning of compromise principles.

Another reason explaining why many conventional programming models have only a limited relevance in policy analysis is the fact that such models are usually based on a set of stringent assumptions, such as: the existence of one known decision-maker, complete information on all relevant objectives and instruments, perfect insight into the impact of policy measures on socio-economic objectives, absence of equity problems and of spatial or social spillover effects, a stable (often linear) structure of the economy, and so forth. It is conceivable that these notions are especially relevant in an integrated economic, environmental, energy and regional policy analysis (see also Issaev et al., 1982).

Integrated economic-environmental-energy modelling has become increasingly complicated over the last decade. Systems theoretic concepts, optimal control models, game-theoretic approaches and multidisciplinary analyses have become necessary tools for economic-environmental- energy analyses. There is a strong tendency towards a more coherent and integrated analysis, in which economic, environmental, energy and regional aspects are brought together in one consistent framework (see Lakhsmanan and Nijkamp, 1980). This need for integrated modelling is mainly caused by the fact that the post-war economic growth paradigm intertwined with technological, scientific and educational progress and rising population numbers, has overlooked inter alia the social and ecological dimensions of this process and hence has led to a serious threat for the man-made and natural environment. This development can not only be observed in the developed countries, but also in the Third World countries, especially in those areas where a rapid industrial expansion is not accompanied by sufficient monetary resources for environmental protection and pollution abatement. Integrated planning and policy models provide essentially some necessary means to restore the balance in favour of more emphasis on environmental dimensions (cf. also Guldman and Shefer, 1981).

As environmental and energy policy analysis usually takes place in a complex field with conflicting goals, various social interests, multiple decision groups and power structures, this analysis should necessarily take account of the multidimensional nature of environmental and energy problems (see Nijkamp, 1980). It is clear, that a broader, socially-oriented view of policy analysis requires an integrative framework for judging alternative policy options. This will, in general, imply that - instead of optimization of the systems outcomes - the attention has to be focussed on providing a rational basis for the policy decisions regarding the system, among others, by revealing conflicts among objectives or groups, by assessing trade-offs among different choice options, by gauging the distribution aspects of policy measures, by identifying efficient solutions and by designing appropriate and relevant methods and procedures for policy evaluation and for compromise strategies. The current interest in interactive multi-objective decision models shows clearly such new trends in designing and employing modern tools for environmental policy-making (see also Hafkamp and Nijkamp, 1982a, and Hafkamp, 1983).

The foregoing remarks lead us to the specification of the following requirements on a relevant integrated policy analysis (see also Nijkamp and Spronk, 1982):

- appropriate and reliable assessment of relevant impacts of policy measures or exogenous changes
- complete representation of the policy area concerned (including its feasible decision space)
- multidimensional representation of the diverse components or modules of the system at hand
- flexible adjustment of the policy analysis to new information or new circumstances
- comprehensible presentation of the results to responsible decision-makers or actors
- appropriate use of available data (including qualitative data)
- consideration of equity aspects and spillover effects
- treatment of trade-offs and conflicts inherent in the choice problem at hand
- use of learning strategies and decision aid tools in a communication between all participants involved in the policy problem at hand
- integrated approach with much attention paid to compromise procedures and institutional dimensions
- emphasis on 'satisficer' principles rather than on 'optimizer' principles.

In the remaining part of the present paper we will make an attempt at developing an integrated approach to regional-economic-environmental-energy policy analysis by using the so-called Triple-Layer Model (TLM) (see Hafkamp and Nijkamp, 1982b). It will be shown that recently developed interactive (integrated economic-environmental-energy) policy models appear to provide a promising perspective for an integrated multiple objective policy analysis. Two elements are central in such approaches, viz. *efficient* (or Pareto) *solutions* for conflicting objectives and *interactive strategies* among analysts and policy-makers. In this regard, it will also be demonstrated that multi-regional input-output analysis is a necessary part of a meaningful and consistent framework for the abovementioned approach.

3. Interactive Multiobjective Programming Models

In this section, a brief introduction to interactive multiobjective decision analysis will be given, as this approach makes up one of the foundation stones of the abovementioned TLM. Interactive decision analysis is one of the fruitful results of modern high speed computer technology. This approach to decision analysis aims at including in a stepwise manner various political (or subjective) considerations in formal optimizing models characterized by multiple policy objectives. After a specification of conflicting objectives and the identification of a feasible (not necessarily the most desirable) compromise solution, a set of additional policy desires (for instance, minimum achievement levels, reference points, or aspiration levels) may be introduced so as to find a new feasible compromise solution that is more satisfactory.

Interactive approaches have several advantages : a closer involvement of actors in the choice process, a procedural view of planning, a 'satisficing' instead of an optimizing behaviour, a greater flexibility by means of simulation experiments or scenario analyses, and a greater potential for practical applications (especially because no policy weights have to be specified). The majority of these interactive approaches are based on a reference point optimization technique, in which an attempt is made at minimizing the discrepancy between a series of points on the efficiency frontier and a reference point. It has to be added that especially procedural interactive policy analyses may be very helpful tools in policy negotiations on conflicting issues.

Some essential elements of interactive multiple objective analysis will now briefly be described.
Suppose a general model containing a vector of decision variables $\underline{z}$ (instruments, e.g.), of policy target variables $\underline{w}$ (with elements w_i, i=1,...,I), of other endogenous variables $\underline{x}$, and of exogenous data $\underline{v}$:

$$\underline{f}\ (\underline{z}, \underline{w}, \underline{x}, \underline{v}) = \underline{0} \tag{3.1.}$$

Then under certain conditions the following reduced form for the targets may be assumed:

$$\underline{w} = \underline{g}\ (\underline{z}, \underline{v}) \tag{3.2.}$$

In addition to (2), a set of constraints (technical, social, political, economic, etc.) on the whole system may be defined:

$$\underline{z} \in K \tag{3.3.}$$

where K represents a feasible area for the variables at hand. Then an efficient (non-dominated or Pareto) solution may be defined as follows: $\underline{z} \in K$ is efficient, if no $\underline{z}^* \in K$ does exist, such that:

$$\left.\begin{array}{l} \underline{w}^* = \underline{g}\ (\underline{z}^*, v) \geq \underline{w} \\ \text{and for some } i: \\ w_i = g_i\ (\underline{z}^*, \underline{v}) > w_i \qquad i \in \{1,\ldots,n\} \end{array}\right\} \tag{3.4.}$$

Consequently, an efficient solution supposes that no other feasible policy exists, which is equally good for all policy criteria and better for at least one criterion (cf. Despontin, 1980; Nijkamp, 1978, 1979). In general, one may impose the condition that any good policy mix is an efficient solution, although it is clear that in practice many inferior solutions may occur. Nevertheless, a meaningful policy analysis should focus the attention in particular on the efficiency frontier (or Pareto curve) in order to identify a policy that will not be dominated by other policies. This is especially important in the framework of interactive policy models which usually aim at identifying in a stepwise fashion a compromise solution located on the efficiency frontier. The identification of a 'satisficing' (compromise) solution is however, a far from easy task.

Fortunately, in the field of mathematical programming and mathematical economics, in recent years much work has been undertaken to formulate operational optimization procedures for problems with multiple objectives (see among others, Keeney and Raiffa, 1976; Cohon, 1979; Rietveld, 1980, and Nijkamp and Spronk, 1981). At present, there is a whole spectrum of different multiobjective methods available, both in the field of continuous programming analysis (see, e.g. Nijkamp, 1979) and in the field of discrete plan and project evaluation methods (see, e.g. Voogd, 1982).
It should be noted however that many of these procedures have not been specifically designed for macro-economic decision-making. The usefulness of these diverse methods and procedures for macro-economic policy analysis very much depends on the way macro-oriented priorities and conflicts can be taken into account. With respect to this issue, it may be meaningful to distinguish these methods and procedures according to the information available on the decision-maker's preferences (see, e.g. Hwang and Masud, 1979). Three cases may then be distinghuished: (1) full information, (2) limited information and (3) no information. Especially in case of limited or zero information, interactive procedures may be very helpful. Many problems in an integrated policy analysis do not require an unambiguous solution that represents once and for all the optimal state of the system concerned: compromise strategies appear to prevail. In the light of the process character of many decision problems, an interactive policy analysis may therefore, be a reasonable and operational approach. This approach is usually composed of a series of steps based on a systematic exchange of information (based on computer experiments) between decision-makers and analysts. Such interactive approaches are normally characterized by the following pair of steps:

- the analysts propose meaningful and feasible (trial) solutions on the basis of a well-defined compromise procedure.
- the decision-makers respond to each (trial) solution by indicating in which respect (i.e., in regard to which effects) the proposed compromise is still unsatisfactory (given their views on mimimum achievement levels, aspiration levels, etc.).

These pairs of steps are then successively repeated, until after a series computer experiments, a final satisfactory compromise solution has been identified. As mentioned before, a large number of interactive models has recently been developed (see among others, Rietveld, 1980 and Spronk, 1981).
Interactive policy analyses based on multiobjective programming methods have already demonstrated their meaning in various policy problems, also in a macro-economic context. They may be regarded as having many significant advantages compared to traditional optimization methods (see Nijkamp and Spronk, 1981).

In the present paper, only one specific type of interactive policy method will be dealt with, viz. the method of displaced ideals (see Zeleny, 1976 and Nijkamp, 1980). It is a method which needs no explicit prior information on trade-offs between targets expressed by decision-makers in the procedure. If they are offered a feasible (and efficient) solution to the multi-objective problem, they only need to choose an objective which has to be improved in value in the next iteration of the procedure. This tentative compromise solution is determined on the basis of a reference solution (the 'ideal' point), which is regarded here as the points on the main diagonal of the pay-off matrix associated with the multiple objective problem. Figure 1 provides a concise presentation of the stages of this interactive optimization procedure.

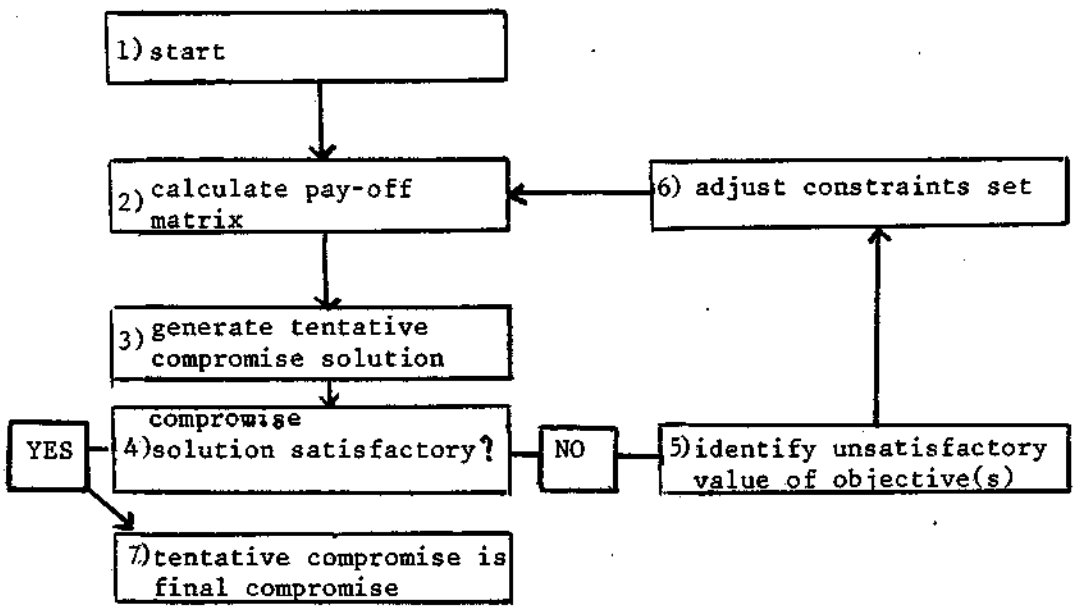

Figure 1. Steps of an interactive optimization procedure.

More details regarding this method can be found in Hafkamp and Nijkamp (1982b) and Hafkamp (1983).

The abovementioned procedure can also be directly related to scenario analyses for macro-economic policy-making. A scenario is a consistent set of prospective values of plans, goals, instruments and exogenous circumstances. Both single and compound may be dealt with. Choices among different scenarios may also be generated by means of the abovementioned interactive multiobjective methods.

4. A Conceptual Triple-Layer Model (TLM)

TLM is a model of a spatial system where economic, environmental and socio-political aspects are integrated. The spatial element implies that the system is analyzed at the level of regions interacting with the national level. Consequently, TLM is a national-regional economic environmental model. TLM is a result of projecting a complex reality on three mutually interacting parallel layers:

- an economic layer
- an employment layer
- an environmental layer.

Several aspects of a complex and multidimensional system can thus be depicted in various submodels, according to their respective different aspects and consequences.

The design strategy of TLM implies a three stage procedure, where first a simple model is constructed, so as to depict the triple layer structure and to delineate the scope and detail of the model (see also Hafkamp, 1983). The second step of the design procedure is the construction of a conceptual triple layer model and is described in the present section; the third step assembling the operational triple layer model, is dealt with in the next section.

The conceptual model presented here is a multi-regional model of an economy where economic, socio-political and environmental aspects of a society are of main importance. Public decision-making and planning in such a spatial system will be analyzed in a way analogous to allocation mechanisms in formalized economies with public goods and external effects (see also Ruys, 1975). We shall explicitly deal with (groups of) individuals belonging to a certain region of the spatial system and to a certain interest group (e.g., environmentalists, labour unions).

Conceptually, the model has the following structure. The spatial system consists of a set of regions:

$$\bar{R} = \{1, 2, \ldots, R\} \tag{4.1}$$

The individuals within the spatial system are denoted by:

$$\bar{I} = \{1, \ldots\ldots\ldots\ldots\ldots I\} \tag{4.2}$$

The set of individuals in a region is written as:

$$\bar{I}_r = \{1_r, 2_r, \ldots I_r\} \quad r \in \bar{R} \tag{4.3}$$

where $I_r \cap I_{r'} = \emptyset$ for $r \neq r'$ and $\bigcup_{r=1}^{R} \bar{I}_r = \bar{I}$

The elements which are of importance for individual decisionmaking are regional income, employment and environmental quality. As notation of attainable outcomes in the system, we adopt:

$$\left.\begin{aligned} s_r &= (y_r, l_r, z_r) \quad , \quad r \in R \\ s &= (s_1, s_2, \ldots\ldots s_R) \\ s &\in S \text{ ; S is compact and convex.} \end{aligned}\right\} \tag{4.4}$$

s is an R-tuple of vectors describing the state of the entire spatial system. $\underline{s}_r$ is a vector describing the state of the system for region r, where

y_r denotes regional income

l_r denotes regional employment

z_r denotes regional environmental quality

Various policy mixes (combinations of regional economic policy, environmental policy, and labor market policy) enable a central authority to "control" the spatial system so as to reach, in principle, any situation which is reflected by an element of S.

Individuals in a region have a "consumption" set which is denoted as:

$$X = \{ \underline{x} \mid \underline{x} = (y,l,z) \in R^3_+ \} \qquad (4.5)$$

As mentioned above, we may distinguish different interest groups. There are various ways of incorporating such groups in individual welfare functions. Here we suppose the existence of twice differentiable, concave individual welfare functions:

$$w_{i_r}(\underline{x}_r) \qquad i_r \in \bar{I}_r \qquad (4.6)$$

Thus, the welfare position of an individual in region r is only determined by income, employment and environmental quality in region r.

In addition, a choice set C is defined that serves as the basis for individuals to decide which objective is the most urgent one and hence should be raised first:

$$C = \{ \underline{c}_{i_r} \in R^3 \mid \underline{c}_{i_r} = (a_1,a_2,a_3) \wedge a_j, \sum_{j=1}^{3} a_j \in \{0, 1\}, j=1,2,3 \} \qquad (4.7)$$

(4.7) means that during each state of th choice process not all objectives can be improved simultaneously, but that only one objective can be increased in value (in other words, a_j is a zero-one variable). The spatial system composed of individuals can now concisely be characterised by:

$$EE = \{ \bar{R}, \bar{I}_r, S, (X_r, w_{i_r}, C) \} \qquad (4.8)$$

Spatial system EE can - from the point of view of individuals - be regarded as an economy with external effects only. The set of Pareto-optimal states PO in this system can now be defined as:

$$PO = \{ s \in S \mid \exists r \in \bar{R}, \exists i_r \in \bar{I}_r : w_{i_r}(\underline{s}'_r) > w_{i_r}(\underline{s}_r) \Rightarrow s' \in S \quad \vee$$

$$\{ \exists r \in \bar{R}, \exists j_r \in \bar{I}_r : w_{j_r}(\underline{s}'_r) < w_{j_r}(\underline{s}_r) \} \qquad (4.9)$$

A state of the system is called Pareto-optimal, if an improvement of any individual welfare position is only possible (i.e., within S) through affecting at least one other individual's welfare position. It should be noted that here an efficiency criterion is defined rather than an equilibrium criterion. The set of Pareto-optimal solutions is also known as the set of efficient or non-dominated solutions.

The presence of different interest groups that want to maximize respectively regional income, employment and environmental quality makes it impossible to identify one single overall best solution. Consequently, formally a multi-decision-maker, multi-objective problem has to be solved so as to achieve a state of the system that is a compromise for the conflicting interests among groups.

This can be done by using the interactive method based on displaced ideals which was described in Section 3. However, this method does not specify a decision rule for identifying a 'most urgent' objective if there are many decision-makers involved. This lack may be overcome by using a voting procedure based on a majority rule. The preference relationships should be interpreted as 'tacit preferences' (preferences of which decision-makers themselves are not explicitly and entirely aware).

Clearly, if all individuals would have a set of known welfare functions, an interactive compromise procedure would be superfluous in selecting an optimal (compromise) state for system EE, since in that case a straightforward traditional optimization approach could be used. We make the assumption however, that individuals are not explicitly aware of welfare functions describing their preferences. We also assume that they are unable to give precise information on their preferences in terms of weights (trade-offs) attached to the various objectives (income, employment and environmental quality). Otherwise, it would be easy for a central government to simply optimize a social welfare function of the type:

$$w(s) = \sum_{r=1}^{R} \sum_{i_r=1_r}^{I_r} w_{i_r} (\underline{s}_r) \qquad (4.10)$$

or to optimize a weighted sum of the objectives, using information on trade-offs given by the individuals.

The steps of the interactive compromise procedure are already contained in Fig. 1. The selection itself of an unsatisfactory value of an objective takes place choosing a 'most unsatisfactory' level of an objective by means of a democratic voting procedure, so that a central authority has to count the votes concerning the most unsatisfactory objectives and next adjust the constraint set accordingly.

A more detailed description of the way a TLM is coupled with an interactive multi-objective procedure is contained in Hafkamp and Nijkamp (1982a).

5. An Operational Triple-Layer Model (TLM)

The operational TLM is composed of three sub-models - one for each layer -: an economic, an employment and an environmental sub-model. A detailed discussion of all equations, variables and data of these sub-models can be found in Hafkamp (1983). In this section we only discuss the mainlines of the various sub-models.

The economic sub-model comprises a national-regional economic model of the Dutch economy. It is the result of coupling the so-called

Secmon-model (see Driehuis, 1978) with a multi-regional input-output model of five Dutch regions (see Appendix, Fig. A 1). Various goal variables are included in this sub-model: inflation, current and capital accounts, and economic growth. Policy instruments are: taxes and public expenditure, monetary instruments, exchange rate, wage and price control and labour market policy. Economic actors are: households, firms, government and other agents.

The relationships between the components of the economic sub-model are described by means of 10 modules:

- production (based on input-output tables)
- final demand (consumption, investment, public expenditure and exports)
- imports (final products, raw materials and manufacturing inputs)
- production capacity
- labor market
- wages and prices
- income
- government expenditure
- social insurances
- monetary systems

An extensive description of the economic sub-model can be found in Hafkamp (1982).

The employment sub-model analyzes primarily the demand for labor at both a regional and sectoral level. For the time being, the supply-side of the labor market is considered as exogenously determined by demographic and social developments. It would be worthwhile however, to include more detailed information on demographic developments, education and training endogenously in the model.

The <u>environmental</u> submodel describes 3 aspects of environmental quality:

1. Emission of air pollutants caused by:
   a. combustion of fossil fuels
   b. process emissions, etc.
2. Concentration of air pollutants (via diffusion)
3. Reduction of emission by:
   a. saving energy, selective growth, etc.
   b. alternative choices of energy sources
   c. anti-pollution technology.

Pollution of water and soil is not taken into account here, nor is any attention paid to the phenomenon of synergetic effects. The following pollution categories are taken into account: sulphur dioxide, nitrogen oxides and dust particles.

The choice of energy source also has an important influence on the emission of air pollutants. For example: SO_2 emissions in the Netherlands decreased drastically after a large-scale introduction of natural gas, but since a switch back to coal or oil took place, a drastic increase occurred. Especially the shift of electricity producers from natural gas to oil, coal or nuclear energy and the further exploration and introduction of alternative energy sources (solar energy, wind, etc.) are of great importance to environmental quality.

The way in which the components of these 3 modules are linked is represented in Fig. 2.

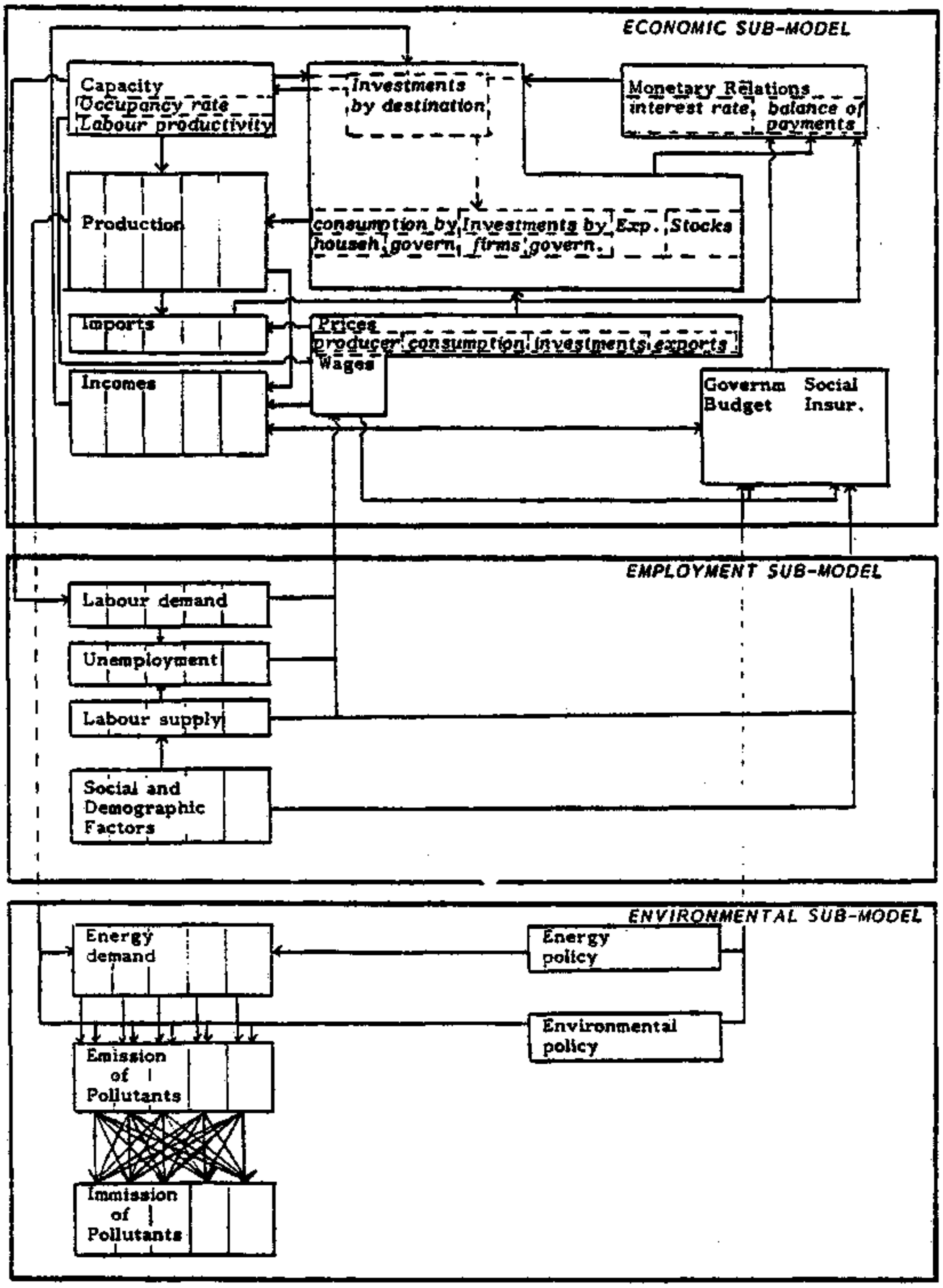

Fig. 2. The Triple Layer Model, its sub-models and their major relations. Source: Hafkamp (1983).

6. Interactive Multiobjective Programming with the Triple Layer Model

Implementing the operational triple layer model of Section 5 has presented us with a number of computational problems. Solving vector optimization problems of this size asks for powerful optimization routines.

In this section, we will apply the interactive compromise procedure introduced in Section 3, to the operational version of TLM. While applying the interactive compromise procedure to the conceptual version of TLM focuses on choice aspects for individuals and on coordination aspects as to public decision-making, its application to the operational version is primarily concerned with controlling the procedure itself and understanding the results obtained.

The model is comprised of five regions (see Appendix, Fig. A 1), with three objectives in each region -- income, employment, and environmental quality. This means that the compromise procedure produces compromises between regional interests as well as between objectives at the regional level. Therefore, a multitude of versions of the procedure could be designed so as to reflect a variety of institutional arrangements under which socio-economic decision-making takes place. These institutional arrangements may imply that a single authority, viz. central government, is the single decision-maker. They may also imply that decision-making is entirely left to regional planners, whose decisions, votes, wishes, and actions are added up only at the central level. Various intermediate arrangements are possible as well, and can be described as multi-level decision-making procedures (see in particular, Rietveld, 1981).

The basic version of the procedure implies separate optimization of all 5x3 objectives at every iteration, while a choice can be made in the procedure between fast covergence(ϕ=1; this parameter will later be discussed) and slow convergence ($\phi < 1$). Simplified versions of the procedure, optimizing separate objectives only at the national level in each iteration and adjusting the constraint set for objectives at the national or regional level, are described in Hafkamp (1983).

Since the Triple Layer Model has approximately 500 endogenous variables, it would be very inconvenient to present the results of each simulation run for all such variables. Throughout this Chapter, we shall express the values of objective variables as index numbers. As a base for these index numbers, a feasible solution for the model is used which is found by setting all instrument variables at a fixed, zero value. The solution which results is found in the interior of the solution set (i.e., it is not an efficient solution). This base solution is given in Table 1.

In order to demonstrate the interactive compromise procedure we will now discuss it step by step -- using Figure 1 as a guideline -- for several consecutive iterations.

1) Start

The problem is prepared for multi-objective optimization using a computed optimization package. In this case the APEX optimization package (by CDC) was used.

The selection of unsatisfactory values of objectives is to be done by the decisionmakers themselves. For example, they may follow a negotiation procedure if they are regional planners. If they are the inhabitants of the regional system, they may use a voting procedure, or any intermediate between negotiating and voting. One possible voting procedure was demonstrated in Chapter 6 when we applied the interactive compromise procedure to the conceptual version of the

	Var	Solution
National		
income[1]	y_N	125572
employment[2]	l_N	3244
env. qual.[3]	z_N	1033
Region 1		
income	y_1	12653
employment	l_1	298
env. qual.	z_1	1301
Region 2		
income	y_2	19433
employment	l_2	561
env. qual.	z_2	1448
Region 3		
income	y_3	28473
employment	l_3	797
env. qual.	z_3	2228
Region 4		
income	y_4	31396
employment	l_4	748
env. qual.	z_4	1687
Region 5		
income	y_5	33615
employment	l_5	837
env. qual.	z_5	3633

Table 1. Basic model solution obtained by fixing all policy instruments at zero values.

1) millions of Dutch guilders in prices of 1973
2) millions of man years in firms
3) thousands of tons of "composite pollutants"

Triple Layer Model. Now, while applying the compromise procedure to the operational version of TLM, we do not have the opportunity of actually having regional planners or voters indicate their choices. Therefore, we will assume some possible outcome of a negotiating or voting procedure.

The interactive compromise procedure thus carried out only provides a tentative scenario for a simulation experiment in multi-objective decision-making.

We carry out the procedure with a convergence speed parameter ϕ = 0.50. The significance of this parameter will be discussed at step 6, where the constraints set is adjusted.

Iteration 1

2) Calculate Pay-Off Matrix

The pay-off matrix is found by optimising consecutively all 15 objectives. Every single optimization of these objectives leads to one column of the pay-off matrix, which is shown in Table 2.

3) Generate Tentative Compromise Solution

In order to generate the tentative compromise solution, it is necessary to identify in the pay-off matrix the maximum and minimum value for each objective. This leads to the first and second column of Table 3. The compromise solution is now found by minimizing a standardized distance function which measures the distance between feasible solutions and the ideal, but unfeasible maximum solution which is given in the first column of Table 3.

		max y_1	max l_1	max z_1	max y_2	max l_2	max z_2	max y_3	max l_3	max z_3	max y_4	max l_4	max z_4	max y_5	max l_5	max z_5
Region 1																
income	y_1	127	116	95	118	116	118	112	118	120	116	116	121	104	116	119
employment	l_1	115	116	114	116	116	112	114	116	111	115	116	110	110	116	110
env. qual.	z_1	84	81	117	96	81	98	83	81	96	96	81	98	82	81	98
Region 2																
income	y_2	128	131	132	133	131	99	127	132	131	126	131	130	111	132	133
employment	l_2	115	115	114	115	116	112	114	115	111	115	115	110	109	115	110
env. qual.	z_2	86	74	83	80	74	113	73	74	83	90	74	83	81	74	83
Region 3																
income	y_3	117	120	117	117	120	118	122	119	91	116	120	115	103	120	118
employment	l_3	116	116	115	116	116	113	115	117	112	116	116	111	110	116	110
env. qual.	z_3	88	78	88	88	78	88	72	78	116	88	78	89	89	78	89
Region 4																
income	y_4	120	122	122	120	122	123	119	122	123	127	122	94	111	122	120
employment	l_4	115	115	113	115	115	112	114	115	110	115	115	109	109	115	109
env. qual.	z_4	88	77	85	90	77	84	77	77	85	82	77	114	89	77	91
Region 5																
income	y_5	119	118	119	120	118	119	116	118	120	120	118	120	127	118	94
employment	l_5	116	117	115	116	117	113	115	117	112	116	117	111	110	117	110
env. qual.	z_5	111	89	109	109	89	110	86	89	107	109	89	109	71	89	120

Table 2: Pay-off Matrix of Iteration 1. Separate optimization of objectives: income, employment, and environmental quality at a regional level.

$$\min d = \left|\frac{127 - y_1}{127 - 95}\right| + \left|\frac{116 - l_1}{116 - 110}\right| + \left|\frac{117 - z_1}{117 - 81}\right| + \cdots + \left|\frac{127 - y_5}{127 - 94}\right| + \left|\frac{117 - l_5}{117 - 110}\right| + \left|\frac{120 - z_5}{120 - 71}\right| \quad (6.1)$$

Minimization of (6.1) leads to the compromise solution which is the third column of Table 3.

		Solutions		
		maximum	minimum	compromise
Region 1				
income	y_1	127	95	117
employment	l_1	116	110	115
env. qual.	z_1	117	81	108
Region 2				
income	y_2	133	99	131
employment	l_2	116	109	115
env. qual.	z_2	113	73	88
Region 3				
income	y_3	122	91	115
employment	l_3	117	110	116
env. qual.	z_3	116	72	95
Region 4				
income	y_4	127	94	118
employment	l_4	115	109	115
env. qual.	z_4	114	77	96
Region 5				
income	y_5	127	94	122
employment	l_5	117	110	116
env. qual.	z_5	120	71	94

Table 3. Iteration 1. Compromise solution, ideal, and least ideal solutions for regional objectives

A more illustrative representation of the results comprised in Table 3. is the diagram of Figure 3. This diagram can be more easily interpreted by decision-makers. We will use it for the discussion of the other compromise solutions. Tables containing the actual outcomes are included in the appendix.

4) Compromise Solution Satisfactory ?

As discussed in Step 1 of this procedure, we did not have actual voting results on compromise solutions reached. Instead we assumed possible outcomes of such procedures. At this point we assumed that, NO, the compromise solution of the first iteration was not satisfactory.

5) Identify Unsatisfactory Values of Objectives

We assumed the following regional objectives to be most urgently improved:

Iteration 1		
Region	Objective to be Improved	
1	income	y_1
2	environmental quality	z_2
3	income	y_3
4	income	y_4
5	environmental quality	z_5

6) Adjust Constraints Set

At this point in the first iteration, the constraints set is adjusted in such a way that in the next iteration the compromise

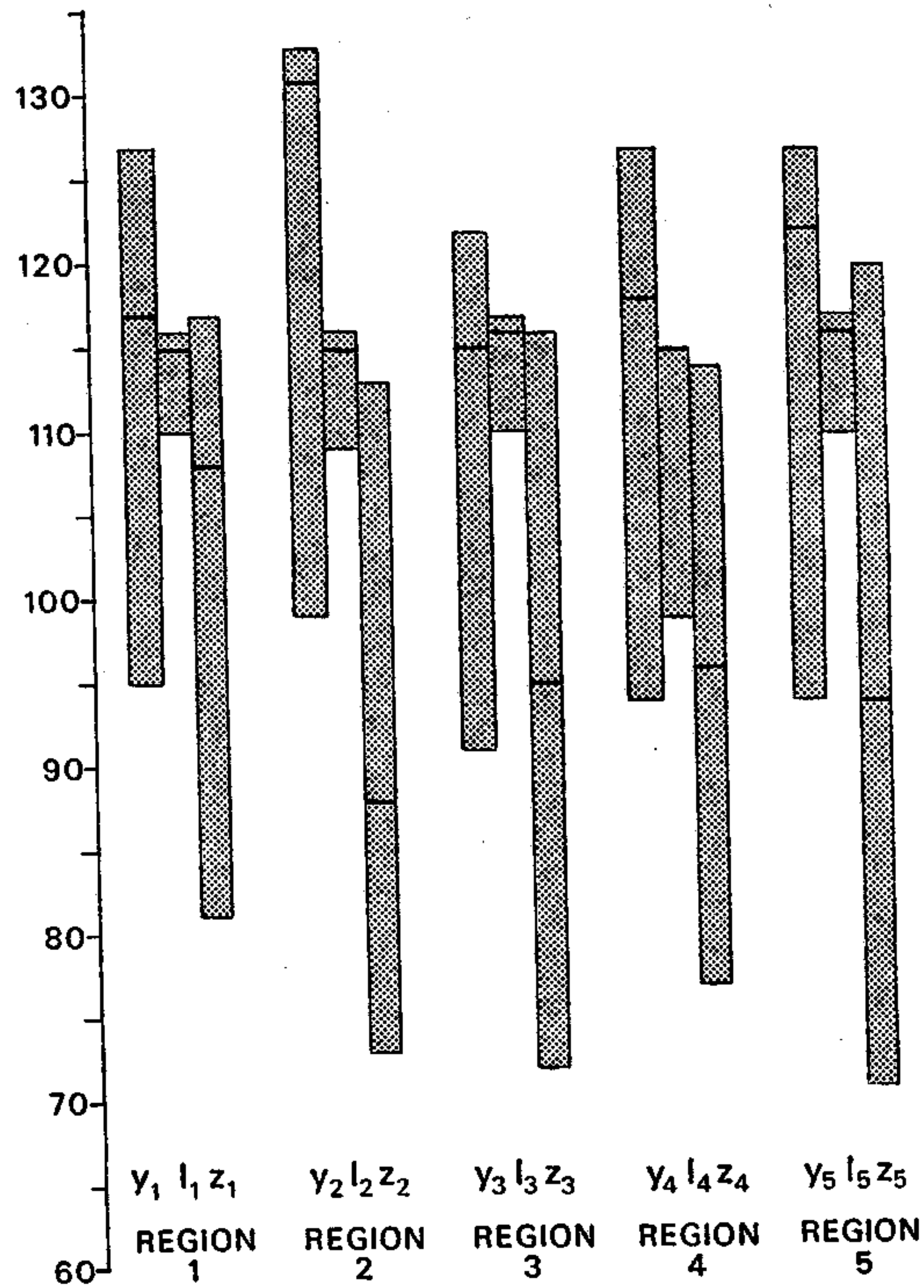

Fig. 3. Compromise Solution of Iteration 1, between minimum and maximum values for regional objectives

values for the objectives selected under the previous step (5) will be higher than the actual compromise values given in Table 3. The general formulation of raising lower bounds of objectives can be written:

$$x^{L,i+1} = x^{L,i} + \phi(x^{C,i} - x^{L,i}); \ \phi\varepsilon(0,1]. \qquad (6.2)$$

where:

$x_{L,i}$: Lower bound on objective x in iteration i

$x_{C,i}$: Comprovise value of objective x in iteration i

ϕ ; Parameter denoting convergence speed.

The convergence speed parameter is to be set at the start of the interactive procedure. A high convergence speed (ϕ=1) implies that from one iteration to the next large improvements are bound for objectives selected at step 5, while a final compromise may be reached in relatively few iterations, as relatively strong constraints are added in each iterations. For the present application of the procedure the convergence parameter was set at .50. Consequently the following lower bounds for objectives were added to the constraints set:

$y_1^{L,2}$ = 95 + 0.50 (117-95) = 106 [1]

$z_2^{L,2}$ = 73 + 0.50 (88-73) = 80.5

$y_3^{L,2}$ = 91 + 0.50 (115-91) = 103

$y_4^{L,2}$ = 99 + 0.50 (118-99) = 106

$z_5^{L,2}$ = 71 + 0.50 (94-71) = 82.5

1) This calculation of lower bounds is illustrative only. Rounded off figures were used.

Iteration 2

2) Calculate Pay-off Matrix

The pay-off matrix is, again, found by optimizing consecutively all 15 objectives. It is included in the appendix as Table A1. The differences between this pay-off matrix and the previous one are entirely due to the fact that the lower bounds derived in step 6 of the previous iteration were added to the constraints set.

3) Generate Tentative Compromise Solution

The second compromise solution is found by minimizing the standardized distance between the unfeasible ideal solution (diagonal elements of the pay-off matrix in Table A1) and the adjusted constraints set. The actual outcomes are contained in Table A 2 in the Appendix.

Figure 4, which is based on those outcomes, can be used to evaluate the changes which occurred due to the unsatisfactory values of objectives identified in steps of the previous iteration.

The compromise values for regional objectives in iterations 1 and 2 give a rough approximation of the existing trade-offs in the operational version of TLM, the most noticeable being those between regional income and environmental quality: An improvement of 1 percent in environmental quality of regions 1, 2, and 5, roughly leads to a 0.5 percent loss of regional income. Regional employment appears to be quite invariant under the choices made, because employment policy can be carried out independently from policies that aim for either economic growth or environmental quality (both of which have favorable impacts on employment).

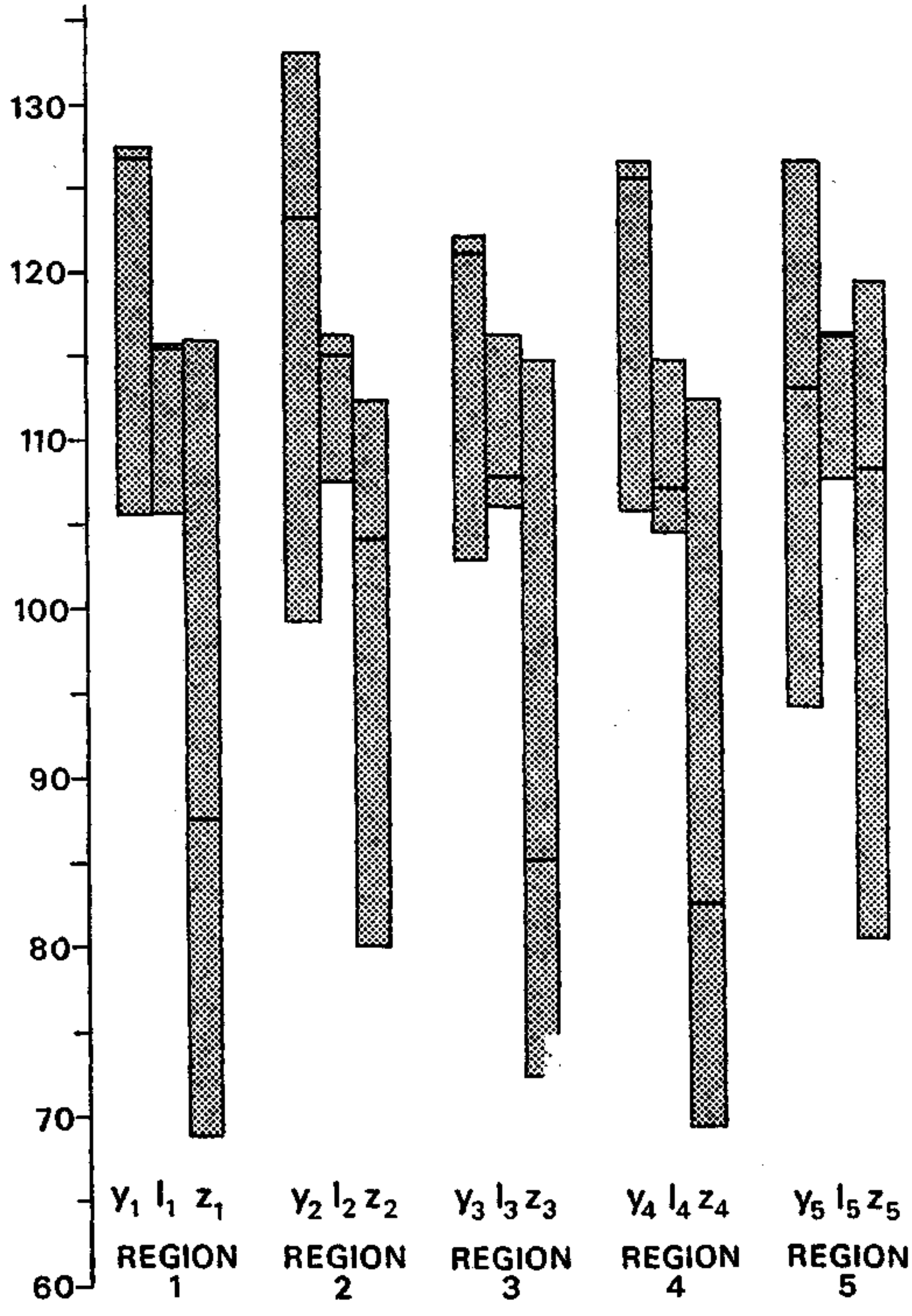

Fig. 4. Compromise Solution of Iteration 2, between minimum and maximum Values for regional objectives

The compromise solution of the first iteration caused the choice of priority in region 1 to move to regional income. As a result, the compromise solution of the second iteration shows that regional income was increased by 8.5 percent. Along with this increase of income came a sharp decrease of the environmental quality indicator by more than 18 percent. It is clear that those people who represent environmental quality for income, will be even more convinced of their choice for environmental quality. There may be a considerable number of people wanting an increase of regional income after the first iteration, but find their desires over-fulfilled: the increase of income is too sharp, while the decrease of environmental quality is too steep. This may result in a general tendency to support the environmental interest in the second iteration.

In region 2 a reverse trade-off was chosen. The first iteration indicated that there was strong support for environmental quality. The actual outcome, an 18 percent improvement of the environmental quality indicator against a more than 6 percent decrease of income, may be very satisfactory to the core of environmentalists but, to many, this may be an "over-exchange". In this region the tendency may be to support the objective of regional income in the second iteration.

In regions 3 and 4, the choice for regional income resulted in a 6 percent improvement of income which is paid off by a decrease of environmental quality of over 10 percent. This choice situation is equivalent to that of region 1. In region 5 a situation has arisen which is comparable to that in region 2. A choice for a better environment results in a strong improvement of the environmental quality indicator by 15 percent which is accompanied by a 7 percent decrease in regional income.

4) Compromise Solution Satisfactory ?

Assume the second compromise solution is not satisfactory.

5) Identify Unsatisfactory Values of Objection

The discussion of the compromise solution at step 3 allows us to assume the following objectives as 'most unsatisfactory' at the regional level:

Iteration 2		
Region	Objective to be improved	
1	environmental quality	z_1
2	environmental quality	z_2
3	environmental quality	z_3
4	environmental quality	z_4
5	income	y_5

6) Adjust Constraints Set

The constraints set is now adjusted in the same manner as in the previous iteration. New lower bounds, to be added to the constraints set,are:

$$z_1^{L,2} = 78$$
$$z_2^{L,2} = 92$$
$$z_3^{L,2} = 79$$
$$z_4^{L,2} = 77$$
$$y_5^{L,2} = 120$$

Iteration 3

2) Calculate Pay-off Matrix

The pay-off matrix is derived in an analogous way to that of the previous iterations, taking into account the lower bounds on objectives which were raised in step 6 of the previous iteration. The pay-off matrix is included in the Appendix as Table A3.

3) Generate Tentative Compromise Solution

Generation of the third compromise solution is identical to that of the previous iteration. Actual outcomes are contained in Table A4 (Appendix), while the diagram of Fig. 5 also represents these outcomes.

4) Compromise Solution Satisfactory ?

In order to demonstrate the procedure to its full extent we, again, assume that NO, the third compromise,is not satisfactory.

5) Identify Unsatisfactory Values of Objectives

We assume that environmental quality is to be raised in regions 1,3,4, and 5. In region 2 an improvement of income is assumed to be necessary.

6) Adjust Constraints Set

For the objectives selected in the previous step of this iteration lower bounds are adjusted according to the procedure described in step 6 of the first iteration.

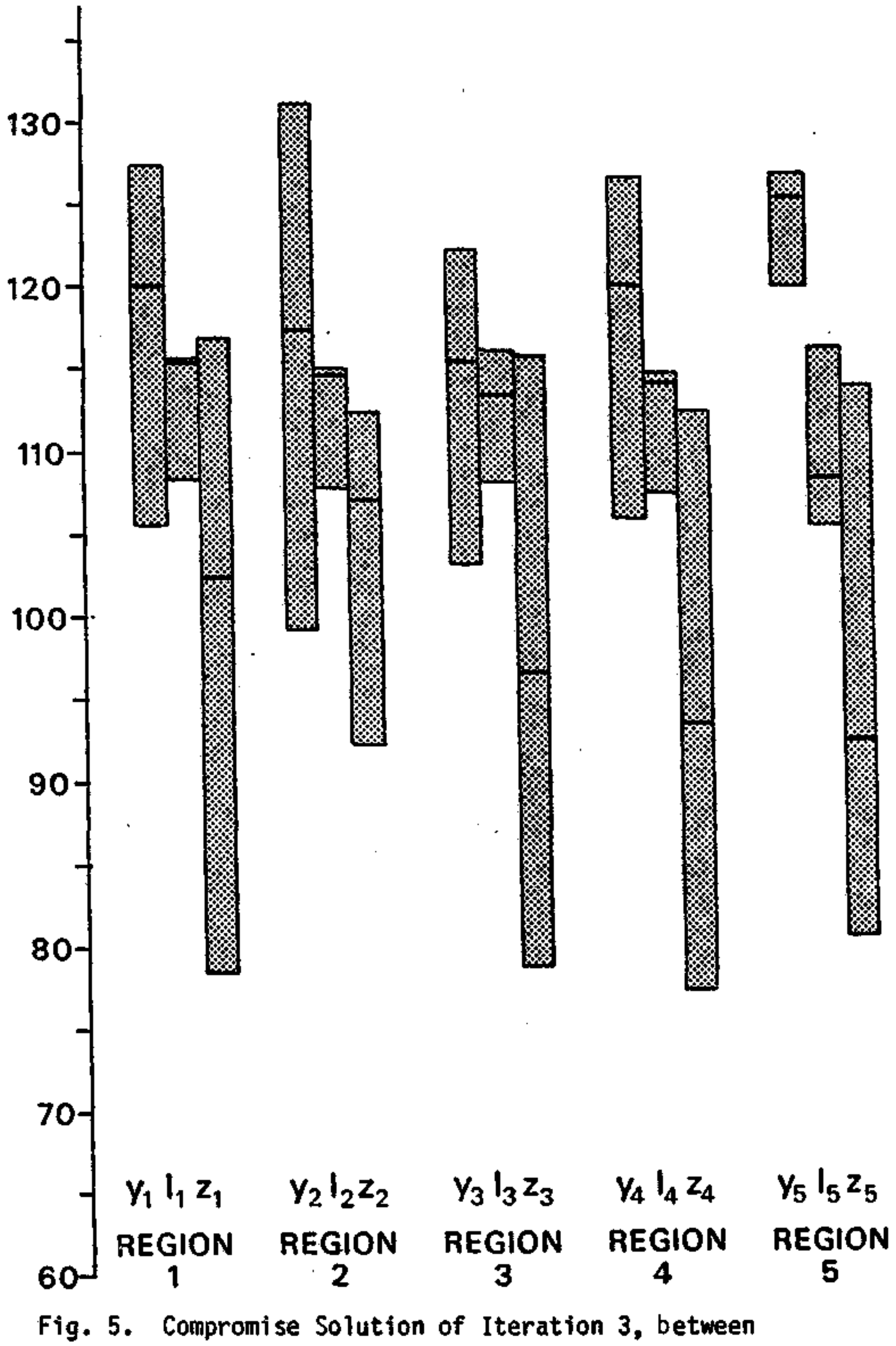

Fig. 5. Compromise Solution of Iteration 3, between minimum and maximum values for regional objectives

Iteration 4

2) Calculate Pay-off Matrix

The fourth pay-off matrix is included in the Appendix as Table A 6.

3) Generate Tentative Compromise Solution

The fourth compromise solution contained in Table A 7 of the Appendix, was used to draw the diagram in Fig. 6. Clearly, from the third to the fourth iteration the adjustment of the constraints set by imposing new lower bounds on selected objectives has induced only marginal changes.

5) Compromise Solution Satisfactory?

Assume yes; of course, the procedure can easily be continued through a number of more iterations. However, we shall not do so.

7) Tentative Compromise is Final Compromise

Clearly, from iteration to iteration, the interactive decision-making procedure not only gives information to the decisionmakers on the actual trade-offs between objectives (as inherent to the model), but also allows the analysts to deduce, from the choices of (groups of) individuals, the actual preferences. However, in order to arrive at an accurate assessment of these preferences, it would be necessary to carry out the procedure over a large number of iterations.

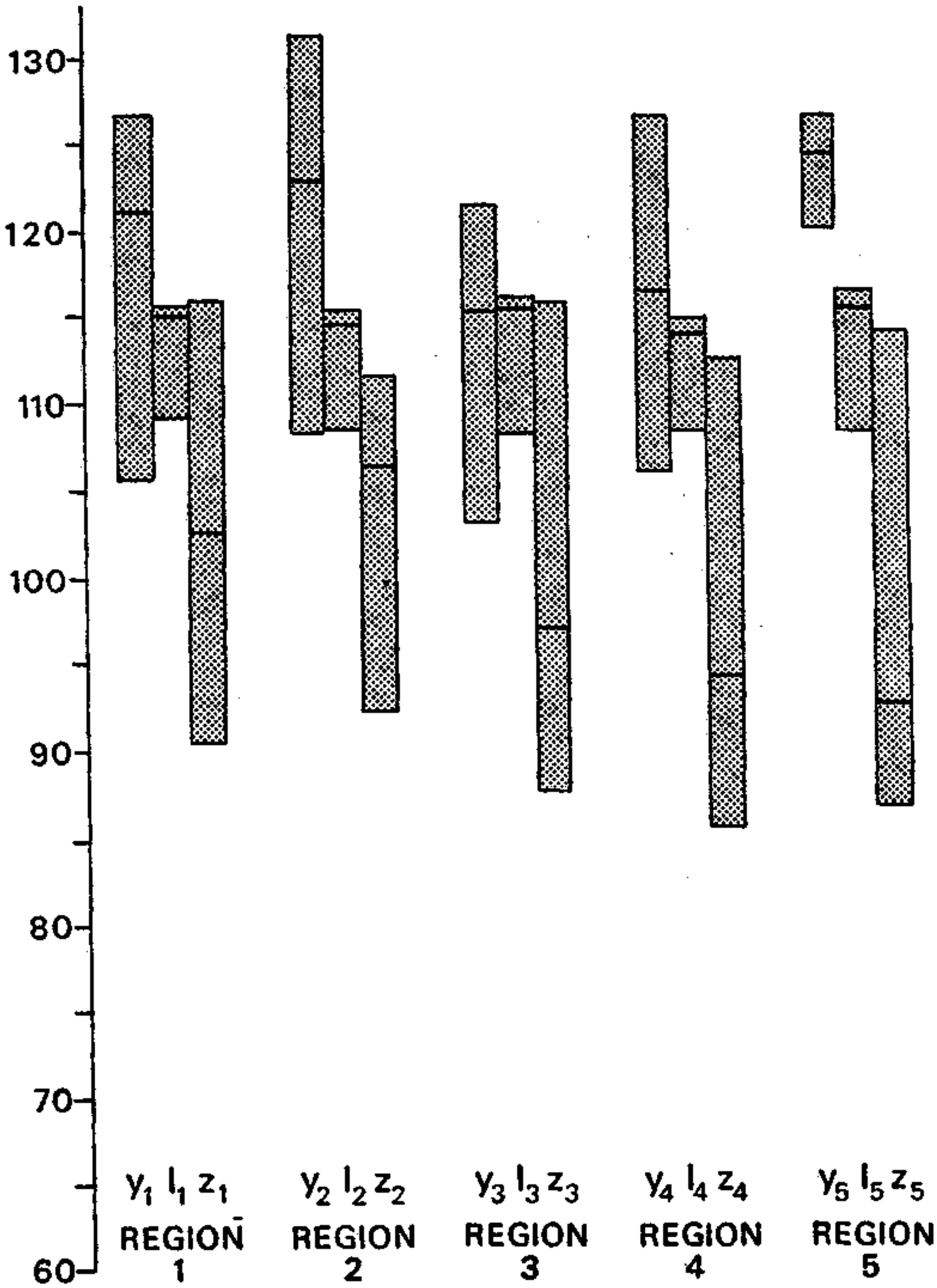

Fig. 6. Compromise Solution of Iteration 4 between minimum and maximum values of regional objectives

7 Concluding Remarks

The interactive multiobjective approaches to integrated economic-environmental decision-making in a spatial system presented and applied in the previous sections, have several advantages over traditional approaches:

- They reflect the process character of complex economic-environmental policy problems; they constitute learning aids for policy-makers as well as for modelers.
- They emphasize an active role of policy-makers in specifying and solving choice problems, inter alia by making policy objectives and trade-offs more explicit
- They are able to take into account the variety and the conflicting nature of policy options or criteria without requiring a prior specification of weights.
- They provide an integrative framework for eliminating less relevant alternatives and for choosing consistent compromise solutions.

The simulation experiments of section 6 indicate that it is possible to adapt the interactive compromise procedure to varying institutional arrangements, even to multi-level decision-making procedures in which a national and regional level are distinguished.

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APPENDIX

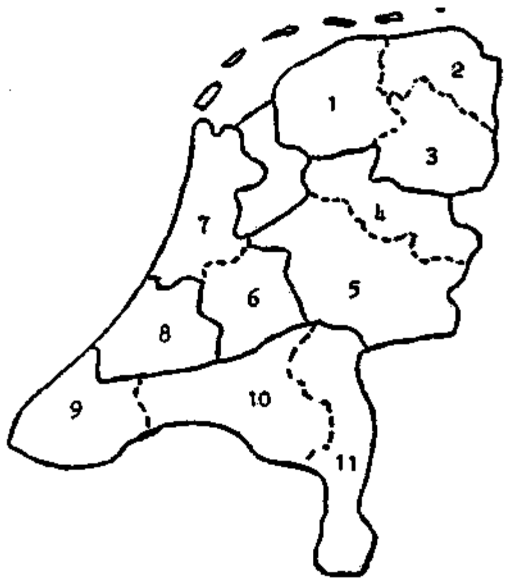

Fig. A1. 11 Provinces of the Netherlands, aggregated to 5 regions

Provinces	Regions
1 Friesland 2 Groningen 3 Drenthe	1 North
4 Overijssel 5 Gelderland	2 East
6 Utrecht 7 Noord-Holland	3 West I
8 Zuid-Holland	4 West II
9 Zeeland 10 Noord Brabant 11 Limburg	5 South

	MAXIMISATION OF:														
OBJ	Y1	L1	Z1	Y2	L2	Z2	Y3	L3	Z3	Y4	L4	Z4	Y5	L5	Z5
Y1	127.4	118.8	105.7	121.4	117.1	124.7	119.3	119.4	124.4	124.1	115.0	119.3	105.7	119.1	126.8
L1	115.4	115.8	114.8	115.4	115.8	112.8	114.8	115.8	111.7	115.4	115.8	111.4	107.7	115.8	111.4
Z1	68.8	85.6	116.0	89.8	86.6	86.0	73.0	78.5	89.1	68.8	86.8	86.3	90.0	78.9	87.8
Y2	124.0	130.0	125.8	133.4	130.9	99.2	121.6	129.8	120.7	123.3	132.3	126.3	104.3	128.8	124.7
L2	115.2	115.3	114.3	115.2	115.3	112.5	114.3	115.3	111.4	115.0	115.3	110.9	107.7	115.3	110.9
Z2	80.0	80.0	88.2	80.0	80.0	112.5	80.0	80.0	87.9	80.0	80.0	87.8	87.6	80.0	120.3
Y3	117.4	120.1	118.6	116.0	119.9	116.9	122.1	119.9	103.1	117.3	119.9	116.1	103.1	119.9	118.3
L3	116.2	116.4	115.4	116.1	116.4	113.4	115.4	116.4	112.8	116.2	116.4	111.8	108.0	116.4	111.5
Z3	74.9	80.1	87.5	89.5	80.8	88.7	72.4	77.5	115.0	74.9	80.9	88.1	96.5	77.2	87.0
Y4	123.2	121.6	122.7	119.7	121.6	122.9	119.0	121.7	119.5	126.9	121.6	106.1	106.1	121.7	125.4
L4	114.7	115.0	113.9	114.7	115.0	112.3	113.9	115.0	111.0	114.7	115.0	110.4	107.5	115.0	110.7
Z4	70.3	79.8	83.7	84.9	80.2	83.8	73.1	77.1	83.7	69.5	80.3	112.8	97.3	77.1	83.8
Y5	120.7	117.7	120.7	119.8	117.7	121.3	117.9	118.1	122.0	118.5	117.7	117.9	127.0	118.1	94.4
L5	116.4	116.6	115.5	116.2	116.6	113.5	115.5	116.6	112.9	116.2	116.6	111.8	108.0	116.6	111.6
Z5	83.1	94.9	106.9	108.1	96.2	108.0	84.2	87.7	105.8	83.1	96.5	107.1	80.9	87.7	119.7

Table A 1. Second Iteration:
Separate Optimization of Objectives
Income, Employment and Environmental
Quality at a Regional Level.

	SOLUTIONS		
	MAXIMUM	MINIMUM	COMPROMISE
Y1	127.4	105.7	126.9
L1	115.8	107.7	115.6
Z1	116.0	68.8	87.9
Y2	133.4	99.2	123.2
L2	115.3	107.7	115.1
Z2	112.5	80.0	104.3
Y3	122.1	103.1	121.4
L3	116.4	108.0	116.2
Z3	115.0	72.4	85.2
Y4	126.9	106.1	125.9
L4	115.0	107.5	114.7
Z4	112.8	69.5	82.9
Y5	127.0	94.4	113.2
L5	116.6	108.0	116.3
Z5	119.7	80.9	108.4

Table A 2. Second Iteration:
Ideal, Worst and Compromise Solutions
for Regional Objectives.

	MAXIMISATION OF:														
OBJ	Y1	L1	Z1	Y2	L2	Z2	Y3	L3	Z3	Y4	L4	Z4	Y5	L5	Z5
Y1	127.4	115.8	105.7	122.0	114.2	126.9	117.9	114.4	124.6	124.8	111.8	121.1	105.7	114.4	125.0
L1	115.4	115.8	114.8	115.1	115.8	113.1	114.4	115.8	112.1	115.4	115.8	111.1	108.4	115.8	115.1
Z1	78.4	98.0	116.0	89.4	98.4	86.0	82.7	97.8	85.5	78.4	98.6	87.4	91.0	97.8	86.1
Y2	123.2	125.7	124.7	131.3	125.7	99.2	116.6	127.5	117.7	120.9	126.8	121.6	106.9	127.5	121.9
L2	115.2	115.3	114.3	114.8	115.3	112.7	113.9	115.3	111.6	115.0	115.3	110.7	108.0	115.3	114.8
Z2	92.2	92.2	92.2	92.2	92.2	112.5	98.1	92.2	94.4	92.2	92.2	97.6	92.2	92.2	96.1
Y3	117.4	120.0	117.7	112.2	120.5	117.7	122.1	119.2	103.1	115.4	120.0	114.4	103.1	119.2	117.6
L3	116.2	116.3	115.3	115.8	116.3	113.6	115.2	116.4	112.8	116.2	116.3	111.7	108.3	116.4	115.8
Z3	82.3	84.7	86.4	90.3	84.8	88.5	78.8	85.0	115.0	82.0	84.7	88.1	92.9	85.0	87.0
Y4	123.3	121.6	123.4	122.2	121.6	122.9	118.4	121.6	122.4	126.9	121.6	106.1	106.1	121.6	122.3
L4	114.7	115.0	113.9	114.3	115.0	112.3	113.5	114.8	111.1	114.7	115.0	110.3	107.9	114.8	114.4
Z4	78.4	84.2	83.7	85.7	84.3	83.8	82.6	84.3	85.8	77.2	84.3	112.8	97.6	84.3	84.5
Y5	120.8	120.1	120.8	120.1	120.1	120.1	120.1	120.1	120.1	120.8	120.1	120.1	127.0	120.1	120.1
L5	116.2	116.5	115.4	116.0	116.5	113.7	115.3	116.5	112.9	116.2	116.5	111.7	108.4	116.5	116.0
Z5	93.4	101.8	105.9	108.7	102.3	108.7	90.9	102.3	101.3	92.2	102.3	102.0	80.9	102.3	114.2

Table A 3. Third Iteration:
Separate Optimization of Objectives
Income, Employment and Environmental
Quality at a Regional Level.

	SOLUTIONS		
	MAXIMUM	MINIMUM	COMPROMISE
Y1	127.4	105.7	121.2
L1	115.8	108.4	115.2
Z1	116.0	78.4	102.4
Y2	131.3	99.2	117.6
L2	115.3	108.0	114.8
Z2	112.5	92.2	107.1
Y3	122.1	103.1	115.6
L3	116.4	108.3	115.8
Z3	115.0	78.8	96.9
Y4	126.9	106.1	120.1
L4	115.0	107.9	114.4
Z4	112.8	77.2	93.5
Y5	127.0	120.1	125.6
L5	116.5	108.4	115.9
Z5	114.2	80.9	92.7

Table A 4. Third Iteration:
Ideal, Worst and Compromise Solutions for
Regional Objectives.

	MAXIMISATION OF:														
OBJ	Y1	L1	Z1	Y2	L2	Z2	Y3	L3	Z3	Y4	L4	Z4	Y5	L5	Z5
Y1	126.8	116.2	105.7	124.3	117.3	123.3	118.3	120.1	124.4	122.3	118.1	118.1	105.7	120.1	123.8
L1	115.1	115.8	114.8	115.1	115.8	113.1	114.4	115.8	112.4	115.1	115.8	110.4	109.1	115.8	115.1
Z1	90.4	97.9	116.0	90.4	95.9	90.4	90.5	90.4	90.4	90.4	94.2	94.1	97.2	90.4	90.4
Y2	121.8	126.7	124.4	131.3	127.0	108.4	117.6	128.5	120.6	120.3	126.9	122.6	108.4	128.5	122.8
L2	114.8	115.3	114.4	114.8	115.3	112.7	114.1	115.3	112.1	114.6	115.3	110.0	108.6	115.3	114.6
Z2	98.1	92.2	94.9	92.2	92.2	111.9	98.3	92.2	96.2	98.3	92.2	96.5	95.6	92.2	92.8
Y3	117.0	118.9	118.3	114.2	118.5	114.5	121.7	117.0	103.1	114.9	118.4	110.9	103.1	117.0	117.4
L3	115.8	116.3	115.6	115.9	116.3	113.6	115.2	116.3	113.3	115.8	116.3	111.0	108.4	116.3	115.7
Z3	88.4	87.9	87.9	91.7	87.9	89.2	87.9	87.9	115.0	88.6	87.9	90.9	101.4	87.9	87.9
L4	114.3	115.0	114.0	114.4	115.0	112.3	113.8	114.8	111.8	114.3	115.0	109.6	108.4	114.8	114.2
Z4	85.5	85.5	85.5	86.6	85.5	87.7	90.9	85.5	85.5	85.5	85.5	112.8	106.0	85.5	85.5
Y5	120.5	120.1	122.1	120.1	120.1	120.1	120.1	120.1	120.4	120.3	120.1	120.1	126.9	120.1	120.1
L5	116.0	116.5	115.7	116.0	116.5	113.7	115.3	116.5	113.4	115.9	116.5	111.2	108.4	116.5	115.8
Z5	108.0	99.7	103.0	108.5	100.4	108.1	107.2	103.5	101.2	108.0	101.1	101.8	86.8	103.5	114.2

Table A 5. Fourth Iteration:
Separate Optimization of Objectives
Income, Employment and Envronmental
Quality at a Regional Level.

	SOLUTIONS		
	MAXIMUM	MINIMUM	COMPROMISE
Y1	126.8	105.7	121.2
L1	115.8	109.1	115.2
Z1	116.0	90.4	102.7
Y2	131.3	108.4	123.0
L2	115.3	108.6	114.7
Z2	111.9	92.2	106.5
Y3	121.7	103.1	115.6
L3	116.3	108.4	115.8
Z3	115.0	87.9	97.0
Y4	126.6	106.1	116.6
L4	115.0	108.4	114.3
Z4	112.8	85.5	94.3
Y5	126.9	120.1	125.6
L5	116.5	108.4	115.9
Z5	114.2	86.8	92.8

Table A 6. Fourth Iteration:
Ideal, Worst and Compromise Solutions for
Regional Objectives.

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