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FUZZY MULTIOBJECTIVE MATHEMATICAL PROGRAMMING

IN ECONOMIC SYSTEMS ANALYSIS

DESIGN AND METHOD

by

LI DA XU

A dissertation submitted in partial fulfilment of the
requirements for the degree of

DOCTOR OF PHILOSOPHY
in
SYSTEMS SCIENCE

Portland State University

1986

TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

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AN ABSTRACT OF THE DISSERTATION OF Li Da Xu for the Doctor of Philosophy in Systems Science presented August 14, 1986.

Title: Fuzzy Multiobjective Mathematical Programming in Economic Systems Analysis--Design and Method

APPROVED BY MEMBERS OF THE DISSERTATION COMMITTEE:

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Economic systems analysis is a systems analysis technique of setting out the factors that have to be taken into account in making economic systems decisions. The inquiring and operational systems of the technique are almost exclusively designed for well-structured systems. In review of economic

systems analysis against systems thinking, there is a growing tendency to discard the analytical approach as inappropriate for dealing with an ill-structured issue. Therefore, economic systems analysis needs both the inquiring and operational systems which are appropriate for ill-structured systems.

The foregoing leads to the introduction of an extensive methodology. Mainly, the weakness of economic systems analysis methodology can be traced to the philosophical paradigm upon which the technique is based. In this study, four main aspects of both the inquiring and operational systems of economic systems analysis are being explored:

1. A new philosophical paradigm is proposed as the foundation of general methodology in place of the traditional Newtonian-Kantian inquiring system.

2. The new philosophical paradigm needs new problem formulation and analysis space; therefore, a multidimensional, synergetic, and autopoietic model is proposed for systems synthesis and systems analysis.

3. The new philosophical paradigm is characterized as a Singerian inquiry, and as a result, Marglin's multiobjective analysis is replaced by a Singerian multiobjective analysis.

4. Markov communication theory and fuzzy sets theory are proposed as tools for handling complexity. Markov

communication theory and fuzzy sets theory are introduced for systems design and multiple objective analysis.

The first three aspects serve as a basis for introducing fuzzy multiobjective mathematical analyses, i.e., the fourth aspect. These refinements in methodology promise to aid in solving current problems not only in economic systems analysis, but also in the related fields of fuzzy multiobjective mathematical programming and systems theory.

This study reports on the first application of a Singerian fuzzy multiobjective mathematical algorithm in economic systems analysis, concluding that fuzzy systems theory, especially Markov communication theory, can realize approximate reasoning in economic systems analysis. Fuzzy modeling offers a deeper understanding of complexity and a means of expressing the insights that result from that understanding; moreover, it provides a means of incorporating subjectivity and adaptation. Therefore, fuzzy modeling increases the validity of the systems approach for dealing with ill-structured systems. The proposed method represents an important theoretical improvement of Marglin's approach. The results, however, also hold practical importance, for they are of practical interest to systems analysts who would improve systems design and multiobjective analysis.

ACKNOWLEDGEMENTS

Great appreciation is extended to the members of the dissertation committee, Dr. Abdul Qayum (chairman), Dr. Ronald C. Cease, Dr. Earl A. Molander, Dr. Robert W. Rempfer, and Dr. Brian I. Stipak for many intellectual debts that I have incurred while writing this dissertation. In particular, I thank Dr. Rempfer for inspiring fuzzy systems theory portion of this study. His exposition of Markov communication theory provided many of the systems ideas presented in this study.

Dr. Molander, Dr. Rempfer, and Mr. Dan Rodgers (with Master in English) are also extended heartfelt thanks for turning the scribble into idiomatic English.

My final thanks go to Ling X. Li, who provided many helps during this study.

Li Da Xu

Portland, Oregon

August 1986

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CHAPTER 1

INTRODUCTION

But the existing scientific concepts cover always only a very limited part of reality, and the other part that has not yet been understood is infinite.

W. Heisenberg [1, p.201]

1.1. Statement Of The Problem

1.1.1. Classical Economic Systems Analysis

Economic systems analysis is a systems analysis technique of setting out the factors that have to be taken into account in making economic systems decision, with the aim of maximizing the value of all benefits minus that of all costs, subject to given constraints. In fact, Paul Samuelson [2], a Nobel laureate in economics, defines economics as a subject for analyzing the costs and benefits of alternative patterns of resource allocation. Thus, economic systems analysis in many ways reflects the essence of economics.

Economic systems analysis may date back as far as the 1780s when Bentham told briefly what his major work was and its significance [3]. It began to flourish in the early 1950s. Over the next two decades, works such as McKean's Efficiency in Government through Systems Analysis, Hitch and

McKean's The Economics of Defense in the Nuclear Age, Quade's Systems Analysis and Policy Planning, Seiler's Introduction to Systems Cost Effectiveness, and Fisher's Cost Considerations in Systems Analysis [4, 5, 6, 7, 8] became representative of the discipline.

Many modern scholars have come to view economic systems analysis as a sophisticated and well-founded technique that examines all prospective consequences of a proposed alternative in economic terms [9, 10]. The technique systematically enumerates all benefits and costs of a particular economic alternative, whether external or internal, tangible or intangible, quantifiable or qualitative, that will accrue to the society.

According to Stokey [9], in brief, the procedure of economic systems analysis consists of the following steps:

1. Definition of the project to be analyzed.

2. Determination of all relevant effects, internal or external.

3. Conversion of all effects into economic terms.

4. Calculation and comparison of benefits and costs.

5. Selection of optimal alternative.

According to Sage [11], similar steps are performed for economic systems analysis:

1. Formulation of the problem. This is generally accomplished by using techniques suitable for problem formulation, including the identification of objectives,

boundaries, constraints, and a value system. The outcome of the formulation mainly consists of alternatives.

2. Identification of the costs and benefits of each alternative. Costs and benefits of each alternative are enumerated. Measures for different kinds of costs and benefits are designated. Economic conversion factors are considered.

3. Collection of data concerning costs and benefits. Information concerning the costs and benefits of each alternative is collected from sources that may include modeling, simulation, and optimization. When similar alternatives differ only in a set of parameter values, it is possible to build a model that ranks the alternatives on a performance scale. The model embraces an optimization procedure that indicates a set of parameter values, yielding the optimal performance.

4. Economic quantitative analysis of costs and benefits. Quantified costs and benefits are expressed in economic units. Market prices or shadow prices are introduced. Discounting is used to convert costs and benefits at different times to present values, allowing comparison.

5. Analysis of qualitative aspects. This analysis usually includes indirect effects such as social, cultural, esthetic, legal, and environmental factors.

6. Communication of results, ordinarily in the form of

a numerical report.

1.1.2. Distinguishing Features Of Classical Economic Systems Analysis

In classical economic systems analysis, the traditional systems analysis tools are often considered to be sufficient and appropriate. Distinguishing features of classical economic systems analysis are as follows:

1. Well-structured systems assumption. a. The number of attributes necessary to characterize a system is limited; b. System is static and does not evolve in time; c. The laws relating the properties of the attributes to the behavior of the system are generally deterministic; d. The behavioral factors do not contribute significantly to systems performance.

2. Objectivity. In accordance with the Newtonian inquiring system, economic systems analysis sets out to describe facts, and then to deduce results from that description. Both the analyst and the decisionmaker are seen as unbiased observers who are likely to define systems objective outside the system. Therefore, it is assumed that the decisionmaker acts rationally in the public interest. The golden rule of allocative efficiency and the utility maximization rule of decision theory are significant examples based on assumptions of objectivity.

3. Abstraction. The study of a system is in terms of

a limited number of attributes and the relationships among them. This approach adopts the Kantian inquiring system, according to which truth is synthetic, i.e., the data and any analytical models based on the reduction are inseparable. Once the essential features of an observation have been reduced to a model, the resultant model can be adapted to realities. Radical abstraction tends to banish the detailed picture which may be described by qualitative analysis.

Conventional systems analysis technique to modeling aims at capturing the aggregate logic of an issue, which is taken to represent the essence of the issue. Aggregation, a technique of economic systems analysis, considers all relevant effects associated with a project during a given time frame, and then determines benefits and costs. Meanwhile, a discount rate is assumed, and the time streams of benefits and costs are discounted to present values. Theoretically, economic systems analysis can associate all the effects with each alternative, and then condense the effects into a single figure, for the purpose of comparing and ranking alternatives.

4. Linear time frame. Economic systems analysis uses a discount rate applied to future benefits minus costs to determine present values.

5. Optimal solution exploration. Economic systems analysis is widely known for its exploration for the

optimum.

6. Problem-solving view. It is assumed that the solution is available for the system being explored.

1.1.3. Two Schools: Systems Analysis Vs. Policy Analysis

From a classical perspective, as summarized by Anderson [12], the purpose of economic systems analysis is primarily to study economic efficiency. Applied systems analysis, too, discusses economic systems analysis in economic terms [11]. Beginning in 1965, a new school represented by Prest and Turvey [13], advocated economic systems analysis as a technique of decisionmaking within a framework which related to political, social, and other non-economic considerations. Prest and Turvey considered it unduly restrictive to define economic systems analysis as a continuation of operations research or systems analysis. Williams [14] points out that non-economic considerations intertwine so inextricably with economic factors, so that economic systems analysis can and must incorporate them, developing beyond mere operations research and systems analysis. These two schools, systems analysis represented by Anderson [12] and policy analysis represented by Prest, Turvey, and Williams [13, 14], have coexisted since the 1960s.

1.1.4. Crux Of The Problem

Economic systems analysis has been successful in assessing well-structured projects since the 1950s. Since the early 1970s, growing numbers of analysts have criticized economic systems analysis for failing to cope with ill-structured issues that involve broader considerations. Most analyses of ill-structured systems leave many questions unanswered. Indeed, this dearth of solutions to socio-economic issues is inherent in the conventional methodology. However, economic systems analysis is still applied to ill-structured issues, and the result is inappropriate policy.

In fact, most of the characteristics of conventional economic systems analysis are incompatible with the reality represented by ill-structured systems (see 1.1.2.). The characteristics of economic systems analysis account largely for the rise of the school of policy analysis.

The function of economic systems analysis, per se, is directly related to its inquiring and operational systems. However, these inquiring and operational systems are almost exclusively designed for well-structured systems. There is a growing inclination to dismiss the analytical approach as improper for dealing with ill-structured issues, arguing that the conventional methodology is insufficient to describe the approximate mechanism of a complex system, and shifting the emphasis of the method from analytical thinking to the approximate description in order to achieve approximate reasoning and meet the challenge raised by ill-structured systems.

Because economic systems analysis lacks both inquiring and operational systems for solving problems in ill-structured systems, the quest for appropriate inquiring and operational systems becomes a paramount methodological issue. This search is the major purpose of the research.

1.2. Significance Of The Study

In the course of time, the characteristics of the theories accepted by science are determined by philosophical paradigms. The Newtonian-Kantian inquiring system has been the methodological core of economic systems analysis for a long time. However, this model does not describe the actual process of economic systems decisionmaking. As a substitute, this study develops a synergetic philosophical paradigm as the foundation of general methodology, accompanied by an appropriate operational system that includes corresponding systems design and optimization.

The study, a response to current trends in economic systems analysis, is the first to develop an inquiring system and corresponding operational system designed for ill-structured issues in economic systems analysis. Its results, therefore, have both theoretical and practical importance.

The major contribution of the study is to the methodological basis and the operational system of economic systems analysis. Furthermore, since economic systems analysis is one of the most important analytical functions in decision support systems, the study also contributes to the problem processing and artificial intelligence phases of decision support systems, especially self-learning and model updating.

1.3. Organization Of The Study

Inquiring systems and operational systems exist in an inseparable symbiosis. This study focuses on four principal aspects of both the inquiring and operational systems with the following objectives:

1. A new philosophical paradigm will be proposed as the foundation of general methodology in place of the Newtonian-Kantian inquiring system.

2. Because the new philosophical paradigm needs specific problem formulation and analysis space; therefore, a multidimensional, synergetic, and autopoietic model will be proposed for systems synthesis and systems analysis.

3. Because the new philosophical paradigm is characterized as a Singerian inquiry [15], Marglin's multiobjective analysis [16] will be replaced by a Singerian multiobjective analysis.

4. Fuzzy systems theory, especially Markov communication theory [17], will be introduced for systems design and multiobjective mathematical analysis.

The first three aspects provide a solid basis for introducing fuzzy formulation. The new philosophical paradigm creates multidimensional analysis and a Singerian multiobjective analysis replaces a Newtonian-Kantian multiobjective analysis such as the Marglin approach; then, the introduction of randomness and fuzziness becomes necessary. In short, the first three phases clarify the randomness and fuzziness in economic systems decisionmaking. The last--the fuzzy algorithm--demonstrates how to deal with the fuzziness in economic systems issues that are characterized by multiobjectives.

CHAPTER 2

SYNERGETIC PHILOSOPHICAL PARADIGM IN ECONOMIC SYSTEMS ANALYSIS

But in fact, we know nothing from having seen it; for the truth is hidden in the deep.

Democritus [18, p.166]

2.1. Synergetic Philosophical Paradigm

As a scientific inquiry, economic systems analysis reflects or mirrors various science-oriented theories. This general framework basically is the deep structure of scientific theories.

The proposed philosophical paradigm claims the functional characteristics of a general theoretical framework of economic systems analysis but is basically antagonistic to the aforementioned features of economic systems analysis in the following way:

Subjectivity

The process of economic systems analysis is fundamentally a process of human activity. Therefore, economic systems analysis is developing along with the subjective activity of human beings. The statement that the trace of subjectivity is indelible in scientific practice [1] seems to hold true for economic systems analysis. The recognition of Heisenberg's celebrated "Principle of Indeterminacy" [1] heralded a new era of scientific thought. As Popper [19, p.6] points out "scientific method holds a somewhat peculiar position in being even less existent than some other non-existent subjects," the ideal and objective principles have been surrendered. The pattern that has been brought to light by economic systems analysis is only a partial one which can be probed by subjective practice under certain spacial and temporal conditions. The probe directly relates to the structure of subjective practice.

Wider Systems, Systems, And Subsystems

This is a conceptual system that allows the economic systems issues to be studied as a complex whole. In performing its functions, a system depends on the input it receives from subsystems to generate useful outputs. The output of one subsystem becomes the required input for another subsystem. This interdependence is important in system functioning. A project can be approached as a system in which an economic subsystem is interdependent with other subsystems in a wider context.

Multiple Reference Frames

Economic systems analysis is no longer a framework consisting of points that form a surface. Rather it is the whole of various reference frames, and the product of certain practice-cognition frames.

Multidimensional Structure

A multidimensional structure is the end product of multiple reference frames. Economic systems analysis, instead of being viewed as a linear system, is now described as a system consisting of composites and autopoietic structure. The bistochastic assumption accepts that a socio-economic system contains multiple realities.

Integrity

Economic systems analysis cannot eliminate societal intervention. Scientific analysis and value judgment become a whole through mediation.

Openness

Economic systems analysis is now characterized as an open system. Its theory is subject to further modification and reconstruction with the advent of new evidence that is incompatible with its basic assumptions. Therefore, it is continually being fed with new inputs that can be so incisive as to shatter the conventional picture. The progress of economic systems analysis is an unending process, and the structure of the framework itself is a dynamic pattern in continuous change.

We observe that the above paradigm with which we are concerned here, in fact, has been accepted in reality. Based on the above characteristics, the evidence, which will be discussed in the following section, points to the fact that the existing concepts fit reality only inaccurately, and that the proposed paradigm complements the conventional paradigm in an appropriate way.

2.2. Proposed Paradigm Vs. Conventional Paradigm

Moving beyond the limitations of the Newtonian-Kantian system will allow us to expand our rational thinking to a deeper level. A systems approach is suggested here as an alternative to conventional method because systems thinking has shown that ill-structured issues are more efficiently handled holistically than analytically. As an extension to the Newtonian-Kantian system, the proposed philosophical view makes it possible to appreciate external and internal perspectives along with the analytical perspective in order to understand a socio-economic system fully. The point is that the well-/ill-structured systems dimensions have to be converted into a multidimensional system which describes the essential features of real world decisionmaking. The main characteristics of the multidimensional perspectives are described in Table I.

As Table I shows, the factors affecting the decision-making can be classified as analytical, external, and internal. The record of external and internal factors can be traced back to ancient times. External factors are a system's numerous determinants external to the decisionmakers that affect decisionmaking. Internal factors are the totality of the makeup of an individual, including

Table I. Multidimensional Characteristics in Economic Systems Decisionmaking

	Analytical Perspective	External Perspective	Internal Perspective
Systems definition	well-structured	ill-structured	ill-structured
Inquiring system	Newtonian-Kantian	Singerian	Singerian
Subject vs. object	objectivity	subjectivity	subjectivity
Goal	optimization of resource allocation, economic feasibility	organizational or social concern/ acceptance	preference, needs
Value system	secondary value [20]	primary value [20]	primary value [20]
Abstraction	reductive quantification	intrinsic impossibility	intrinsic impossibility
Mechanism	cause-effect	interaction	interaction
Time frame	linear	nonlinear	nonlinear
Measure	market-price	non-market price	non-market price
Decision criterion	optimal	quasi-optimal	quasi-optimal
Observability	objective analyst & decisionmaker	interest group [21], goal displacement [22]	cognitive tunnel
Process	problem-solving	problem-shifting	problem-shifting

beliefs, values, motivations, and behavioral modes; obviously, they influence how a decisionmaker perceives, imagines, thinks, wills, and acts. The definition of external and internal factors here is broader than that suggested by authors such as Stokey, Andersen, and Linstone [9, 23, 24]. It is difficult to discover the laws that govern external and internal behavior. Human beings act in ways that can either conform to or disprove proposed behavioral laws. The ignorance of human behavioral mechanisms raises the possibility of rejecting any economic or engineering optimization. In describing both external and internal factors in economic systems analysis, analytical tools prove inadequate in modeling since many of the determinants of behavior are random and fuzzy.

The aim of the following discussion is to illustrate and compare the new paradigm and the Newtonian-Kantian system (see 1.1.2. and 2.1.).

Ill-Structured System vs. Well-Structured System

Most projects emerge from processes joined with complex structures that combine human and their environment with different artifacts of human, society, economy, and technology. The objectives and constraints surrounding projects differ in many important aspects from those prevailing in a well-structured system in terms of dimensionality and randomness. In the public sector, there are signs of ill-structured problems everywhere.

In many cases, intuitive judgment must rule.

Subjectivity vs. Objectivity

The inconsistency shown by decisionmaker in decision space indicates that a decisionmaker does not always behave in accordance with an unique, objective preference function. A construction of an observed system is constrained by the perceptions and values of the observer. Even if such a construction distinguishes the system, it is still relatively close to its own limits. Foerster [25] indicates that the perception of a system is a part of the system, not external to it. Boulding [26] stresses that the formation of a new image is a function of the structure of existent images. The reality is being computed continuously and its eigenvalue is only a fuzzy representation.

Therefore, observation is a function of the observer plus the observed. In view of this inescapable subjectivity, the analyst is one of a number of important inputs, rather than a static, objective observer. In this sense, economic systems analysis cannot be objective. Analytical results are unlikely to be replicated by different analysts, because the value judgments-an uncontrollable variable-are indispensable and unavoidable elements in the analytical process. Here analytical results can be reasonably considered as the function of a fuzzy image.

The implication to the economic systems analysis is that the human cognitive system is largely subjective. Subjectivity is not necessarily in the best public interest. Bias can be introduced by the analysts as well as the decisionmakers. Both the analyst and the decisionmaker must be mindful of the risks posed by their subjectivity. A self referential system requires an ethical feedback system to adjust the biases involved in the analytical process.

Systems Concepts vs. Economic Feasibility

There is little sign of a serious quest for a reappraisal of the systems as a whole. However, the proposed paradigm emphasizes the systems concepts. The study of a project in isolation from its systems framework does not yield essential insight. In a general characterization of the immediate determinants of project decisionmaking, an abstract concept such as "benefits maximization" is less useful than the concept of systems--not because the latter is less abstract, but because it is less restrictive and closer to reality in the formulation and solution of practical issues.

It may be reasonable to disregard the known causal factors for the purposes of simplifying mathematical calculation. However, there is no warrant for ignoring the systems concepts in a statement of the theory of economic systems analysis. The initial estimated cost of a project may be substantially higher than its full cost, while the initial estimated benefits may be substantially lower than the real benefits. An alternative, if implemented, may have many consequences caused by the motion of subsystems which can be positive, neutral, or negative to system objectives. A basic contradiction residing in economic systems analysis is that no matter how rational it is from an economic point of view, the economic systems issue is a systems decision issue, therefore, economic analysis is, at best, a part of the complete analysis.

The systematic thesis claims that only with a systems view is it possible to find real objectives and constraints. Therefore, the interactions among subsystems, systems, and wider systems is of great importance in exploring the real decision process. A project ought to be studied as a system open to such interactions.

Multiple Reality vs. Optimization of Resource Allocation

Optimization of resource allocation is the main criterion of economic feasibility. However, multiple realities exist. Kneese [27] provides an example which exposes the contradiction between resource allocation optimization and public appeal. Economic systems analysis, in fact, is an evaluation effort that has been developed to deal with complex, ill-structured issues. Holling [28] emphasized that most complicated systems seek resilience instead of efficiency. Efforts taken to determine an unique optimal solution to an economic systems issue which consists of a great number of variables are probably doomed to failure. Optimal solutions by multiple returns methods, or benefit-cost ratios may cause bifurcation in problem solving, i.e., the analytical perspective tends to conflict with external and/or internal factors.

The issue being modeled is ill-structured, such that a beautiful mathematical model is limited despite its elegance. Obviously, the optimization of a project can only be obtained if the subsystem state matches the system state; otherwise, an optimization, at best, is only a quasi-optimization.

Multiple Reference Frames vs. Abstraction

A common criterion for evaluating projects is that a meaningful comparison of all effects is possible only when all inputs and outputs can be expressed in terms of a common unit at a certain point in time and this criterion is strongly supported by abstraction. In practice, to quantify all effects and convert them into an economic measure is beyond the capability of conventional methodology.

The aggregate approach has serious deprivations. First, reduction erases considerable information and the details have to be de-intensified, for instance, when undesirable distributional effects cannot be corrected by transfer payments. Second, a single economic measure depends on the value assigned to effects when they are perceived and on the assumptions by which commensurate units are ascertained. The judgment and assumption are fuzzy and may lead to a value system which only slightly relates to the reality. Moreover, the reduced figure is dependent on several measurements, each is subject to error, and therefore, the final figure necessarily incorporates a combination of these errors. Third, serious theoretical and practical problems arise when there are multiple decisionmakers. Finally, a single objective function is often used to approximate essentially multiobjective situations. Accordingly, objects cannot be meaningfully reduced to terms which will allow precise quantification, and reductive modeling only reflects partial reality.

In a project, the inputs are from all interrelevant sources; the outputs are a compound substance of the inputs. The after effects continue beyond the project life, such as higher order effects, resilience, and intergeneration discounting. In most cases, one common unit is insufficient for expressing all inputs and outputs. A solution to an economic systems issue that is simplified and possibly made amenable to calculation by aggregation may not be an appropriate solution to the original problem. Rourke [29] indicates that many public programs proved resistant to quantification. Dasgupta [30] recognizes that there are serious limitations for ignoring externality in economic systems analysis. Hoos [31] lists two economic systems analyses of education and health programs in which the traditional reductive modeling led to "suboptimization" and "piecemeal fragmentation". Self [32] indicates the unrealistic and even artificial degree of precision in the evaluation of an airport.

As Table I shows, a systematic view leads us to focus on more complex factors.

Multiple Reference Frames vs. Market Value

The expression that all the items of input and output can be expressed in terms of market value remains an ideal solution. Many items of input and output certainly cannot be expressed in terms of market value. Non-divisibility is one characteristic of environmental goods that makes it difficult to obtain economic value directly. Even if the price is available, it may not perfectly reflect value. If the emphasis is to be placed on external and/or internal considerations, market prices are just not reliable as a basis for developing value estimates of the consequences of decisions. For many large-scale projects, even when it is claimed that the market price is available, caution is to be exercised in using it as a basis for estimating money expenditure implications, since it involves various considerations other than monetary criteria. Therefore, the application of the principle of market price is complicated.

Multiple Reference Frames vs. Discounting Rate

In analytical perspective, all the items of input and output can be stated in terms of equivalent values at any particular discount or interest rate discounting backward or compounding forward. An economic system is subject to inflation, recession, and depression. It is a complex system consisting of many different elements which are constantly changing. Many factors should be viewed not as static, but as dynamic, with some units being continually created, and some others being phased out. The dynamic time frame suggests a nonlinear perception of time. The function may have continuous partial derivatives. However, the rationale for keeping other independent variables constant is lack of sufficient grounds. Even the existence of these partial derivatives is not enough to guarantee the continuity of the function.

Besides, different decisionmakers may have different time preferences, and some have a negative discount rate. The attainment of present objectives can be juxtaposed to potential future objectives, and these may not be conveniently expressed through a simplified discount rate.

In addition to the deficiency of an analytical perspective, the weights put on the rational analysis by decisionmakers are always insignificant [33, 34, 35]. The final decision may not be based on analytical criteria, the more important consideration may be embedded atmosphere. Common "Weltanschauung", moral standard, and value system unify all forces under the universal philosophy and direction, and finally a prevailing view is created.

Most economic systems analyses require both analysis and judgment. Analysts usually introduce the analytical perspective. As the solution procedure progresses, aspects of a problem arise that cannot be considered by analytical perspective, and in most cases, they are of critical importance. The choice of allocating scarce resources still remains essentially judgmental in character.

External Factors

Standard operating procedures (SOPs) represent intuition derived from organizational structure and dynamics, and often take the form of worksheets for the justification of projects.

The "goal displacement" treats the engineering project as an external suboptimization [22].

Internal Factors

Decisionmakers tend to be cognizant of only a few objectives. The number of factors under consideration at any moment is reduced until what is left is manageable.

Internal factors are often involved in environmental goods. The demand for environmental goods can be influenced by consumers' perceptions, preference, and attitudes. The views on environmental goods can be the trade-offs of various variables with imprecise characteristics.

The interaction among analytical, external, and internal factors characterized by high dimensionality, nonlinearity, and complexity is the complex whole on which economic systems analysis is based. The choice made by the decisionmaker is influenced by many factors and various patterns of interaction. The triadic model suggested by some authors omits the function of the interaction. The tetrahedron is the unique symmetrical set of minimum interrelationships in the choice of a model. In this interaction, the behavior of a whole cannot be predicted by the characteristics of any of the subsystems' separate parts (see 3.2.1.).

The above exposition demonstrates the need to use analytical, external, and internal perspectives in conjunction, and to avoid the exclusive use of one or the other.

2.3. Prospect For Methodology

Economic systems analysis is not only a systems analysis technique, but also a way of revealing complex reality. The traditional analytical modeling fails when it is applied to ill-structured systems since it is little more than an appreciative system, a mechanism which maintains well-structured relationships and eludes ill-structured ones. It tends to design the total system at the level of an economic subsystem. Though many authors provide valuable contributions to the field, the conventional methodology can be criticized for not being adequate to deal with the difficulties posed by ill-structured issues.

The main idea of the general systems approach is to develop a methodology capable of explaining the composite picture, consisting of various subsystems. Economic systems analysis leaves no room for a systems approach from the Newtonian-Kantian inquiring system. Therefore, a systems approach is invoked to represent systematic methods which differ from pure Newtonian-Kantian inquiry. We attempt to make economic systems analysis more applicable to the problems in the real world, where external and internal factors are both complex and obscure. As a result, economic systems analysis needs to be broadened and shifted from the conventional systems analysis to policy analysis. The proposed systematic methodology is based on the philosophical paradigm described previously and has the following characteristics:

1. Pragmatic view. Systems engineering is referred to as an element of organized, creative technology. Economic systems analysis is an organized, constructive activity: organized in that there is a pattern of analysis; constructive in that it constructs a system to meet a realistic need. Economic systems analysis and reality exist in an inseparable symbiosis. In economic systems analysis, the goal is to construct models that are closer and closer approximations of reality. The ultimate objective of economic systems analysis is not just to discover economic efficiency, but also to get the project accepted and

implemented. The objective is to search for an appropriate course of action instead of proposing solutions which may turn out to be not only inadequate but possibly inimical to the system.

2. Systems characteristics. The focus here is a deeper understanding of economic systems issue as a socio-economic issue. The emphasis is on a holographic, panoramic description. The analysis should be related to systems framework. It is necessary to eliminate the inferior alternatives evaluated in multidimensional analysis; however, these alternatives may rank very high on an economic scale. The decision to adopt a project depends both on analytical properties and systems characteristics.

3. Learning, adaptation, and quasi-optimization. The emphasis here is on learning, adaptation, and quasi-optimization, which improve the efficiency of decisionmaking and bridge the gaps among multidimensional perspectives. On one hand, the process uses systematic thinking to understand and intervene in real-world complexity; on the other the process itself is implemented as a participative, interactive, and iterative one. Such a system has the following characteristics: a. It is a non-linear system with time-varying parameters, therefore, it offers the possibility of substantially increased systems performance when inputs are time varying; b. It is a complicated adaptive system that adapts in the face of changing wider

systems.

4. Quantitative vs. qualitative. Both quantitative and qualitative concerns come into the analysis. The analysis provides insights into the nature of the issues by using Markov communication theory and fuzzy sets theory as a response to "neglect of the subjective elements" [31]. The fuzzy description allows the complexity of the issues to be appreciated. There are many occasions in economic systems analysis when random and fuzzy data are available. It is possible to manage the complexity of the issue to an approximate form both quantitatively and qualitatively.

5. Systematic feedback. The method itself is a learning, adaptation, and quasi-optimization system, and within the system it maintains multiple reference frames. It asserts at same time that such models are the representation of partial reality, i.e., an incomplete picture of various ways of perceiving the reality. For existing systems approach relies in the end upon finite systems which, however synthesized, can not be free of the constraints of finiteness.

Economic systems analysis is defined here as a structure of self-interstabilization in terms of a complex of perspectives operative in multiple degrees of freedom in resource allocation.

Economic systems issue is a socio-economic issue. The proper way of facing it is to seek an appropriate combination of mathematical systems theory and behavioral theory that can resolve ill-structured issues that involve complex interactions among analytical, external, and internal perspectives. In the next two chapters, the proposed hypothetical, multidimensional interaction and fuzzy multiobjective mathematical programming are discussed as two aspects of special relevance to economic systems analysis [36, 37].

In view of the new philosophical paradigm, the following transition phase analogy seems instructive.

Table II. The Major Characteristics of Economic Systems Analysis: 1950s-1980s

Conventional Method 1950s-1980s	Proposed Method 1980s-
economic system	socio-economic system
subsystem	whole
optimization	learning, adaptation, and quasi-optimization
points and surface	functional space [38]
partial reality	partial reality towards integrity
fixed framework	progressive activity
analytical mathematics	imprecise & analytical mathematics
two-valued logic	bistochastic process [17]
objectivity	subjectivity
reductive	holographic
doctrine	way of thinking
final rule	infinite inquiry

CHAPTER 3

SYSTEMS DESIGN IN ECONOMIC SYSTEMS ANALYSIS

The interaction is the ultimate cause of the event.

Friedrich Engels [39, p.574]

3.1. Multidimensional Frames

The pluri-model and hierarchical holographic model have already been developed [40]. This chapter proposes a multidimensional, synergetic, and autopoietical model. "Synergetics" was first coined by Haken [41] in the 1970s to describe physics, but here it is, for the first time, applied to economic systems analysis. In addition to synergetics and related concepts, such as order parameter, critical point, and phase transition, original concepts are introduced, such as general interaction, free energy, higher order substance, the transit of information, boundary, and systems dynamics in ill-structured systems decisionmaking. Applications of the proposed model to economic systems analysis are also suggested. "Autopoiesis" was first coined by Maturana [42] in the 1970s to describe the process of self-renewal and self-maintenance characteristic of living organisms. Here the term is introduced in a new context to describe the self-sustaining characteristics of multidimensional system.

Economic systems analysts long have been searching for a problem space of incorrect dimensionality, with an inadequate list of elements in the state vector defining the system. The economic optimization pertains to only part of system, so the analytical perspective is limited in number. The proposed paradigm permits various perspectives. Suboptimization of any frame, moreover, can diminish the system's effectiveness because the objectives and criteria for subsystems can so easily be chosen in ways inconsistent with those of the system. Economic systems analysis designed to pursue an economic optimum often conflicts with other subsystems. In this sense, it is pointless to expect sound analysis based on economic criteria alone. There is, however, a possibility of finding the truth at a different position [1]. It is the whole that exhibits systems behavior; the parts only exhibit functions that contribute to the purpose of the whole. The parts have perspectives of their own, but the perspective of the whole is unique and subsumes that of the parts.

In economic systems analysis, all relevant reference frames need to be incorporated and taken seriously in a formulation framework. There will be no exact, two-valued logic description in multiple reference frames. A typical economic systems analysis takes the form of finding the quasi-optimal decision with respect to a multidimensional system. As an example of quasi-optimization, in the fuzzy multiobjective algorithm (see Chapter 4), the objective and constraint can be revised within the context of the state of system so long as the decisionmaker believes it is effective in systems perspective. The further analysis is pursued by fuzzily comparing alternatives. The purpose of comparison is to discover the approximate range of trade-offs which will be acceptable for systems effectiveness.

The multidimensional approach which explicitly recognizes the importance of both external and internal perspectives is more realistic than the economic optimization model. Evaluations can partially rely on mathematical models, but subjective judgment is a pivotal input. The breadth and depth of the analysis encourages us to move beyond mathematical economics and convert from maximizing subsystems objectives to optimizing systems objectives.

3.2. Multidimensional Structural Analysis

3.2.1. General Interaction Process

Since the theory has been developed in natural-artificial systems interaction, therefore, a general explanation of the interaction between human systems is indispensable. In the structural representation, a new perspective is advanced for shifting the view from simple cause effect relationships to multiple interaction.

Comprehending the interaction of perspectives in decisionmaking is the aim.

A multidimensional perspective system consists of subsystems that are in interaction, in transit from disorder to order or vice versa. It is a living system in constant motion whereby energy and information are processed.

In this complex system, a. the causal connections among recent inputs and ongoing outputs, i.e., higher order relationships, are too fast to establish in terms of Mesarovic's definition [43]; b. the properties of the dimensionality cannot be explained by a superposition of the actions of subsystems; c. multiple configurations of reality are available [17].

In a sense, multidimensional frame is an intricate, evolving game with a variable number of players [38], each of whom possesses free energy and draws an unique configuration of numerous attributes. They are organized into various subsystems, all relating to the dynamic processes. In reality, the game is played in a system of extreme complexity. The mechanism, therefore, must have sufficient energy available to provide the driving force, and in order to move the perspectives, forces should act on the frames. The formation of a mosaic of perspectives in relative motion with respect to one another is a consequence of these forces. The subsystems are continuously in kinetics. Under the influence of continuously supplied energy, one or more reaction processes are superior to others. Those favourable processes then reinforce each other more and more, growing continuously. Eventually, they run over the other forms of motion. Those new processes of motion thus imprint a macrostructure on the system. The new state thus achieved by the system is of a higher order. The dynamic principle is that the kinetics depends on the substitute process of the subsystems. Those of the highest substitution rates that take the superior positions usually determine the macrostructure. The different rates of substitution of individual motion result in the structure that prevails, implying a constant substitution among the complex motions.

In the interaction, any object in one subsystem probably affects objects in another subsystem. In the system theory, interaction is assumed to occur between entities. But in reality, interactions can occur among interactions as well. These complex, higher order interactions are generally ignored since the existing systems approach is incapable of coping with higher order relationships. However, a general interaction explanation is necessary for macrostructure theoretical development. In order to understand the behavior of the system, the concept of interaction is explained here by a mathematical model. The hypothetical explanation leads to a topological and kinetic understanding of the final outcome in a decision process.

The economic systems issue, in which many factors interact in many ways, is extremely complex. Costs and benefits are much more than the influx and outflow of physical resources, for both may be the outcomes of interaction among all relevant factors. Most decisionmaking processes in economic systems can be attributed to the interaction of perspectives. Analytical, external, and internal perspectives all create a final outcome through their relative motion and interaction. Many well-known historical facts are available to support this point of view. Zhang Wentian, former leader of Chinese Communist Party wrote that Mao Zhedong's personality and some personal random events always affected significant economic policy-making [44]. A comparison of the Carter Administration's attitude to the 56-inch natural gas pipeline project, and that of the Reagan Administration is another striking example [45].

Since the decision systems are in constant interaction, it is impossible to define an appropriate systems objective without knowing a great deal about the system dynamics. This knowledge can be derived only from a multidimensional, synergetic analysis, which encourages full understanding of the decisionmaking process. In a synergetic analysis, objectives, constraints, and value systems are scrutinized in a synergetic way. An alternative solution which may first seem acceptable in the analysis, on further exploration can lead nowhere or prove counterproductive. The original systems components may be substituted by new ones.

In summary, the purpose of this chapter is to explore the economic systems issue at a depth sufficient to give both the analyst and decisionmaker an idea of multiple dimensions and synergetic structure, and identify the possible scope of objectives and alternatives. Multidimensional, synergetic analysis provides a framework for decisionmaking that admits the dynamical contribution of relevant aspects. It is in this system that both quantitative and qualitative data are collected and analyzed, and the final decision begins to take shape: the initial order is created.

Parts of the literature on multidimensional perspectives deal with ill-structured systems, but the majority concentrates on static rather than dynamic properties. In fact, the multidimensional motion is a dynamic process (see pp. 31-37).

Synergetic Information Processing Process

Information processing in decisionmaking can be represented in the following way:

Set E as a set of implicitly defined formal objects, reflected in the systems space of $E_i = \{e_1, e_2, e_3, e_4, e_5, e_6, e_7, e_8, e_9, e_{10}\}$ with input and output,

(1) $e_1 - e_3$

e_1 IW; input from wider systems

e_2 S; subjectivity

e_3 R; reception

The characteristics of $e_1 - e_3$ can be as follows:

(1)between IW and S, composition or differentiation.

(2)for S(R), composition or differentiation.

(3)for R, certainty or uncertainty.

(2) $e_4 - e_8$

e_4 IS; information space

e_5 EI; expression of information

e_6 IC; information processing

e_7 IP; intelligence potential

e_8 SGM; signal-grammar-mathematics

This is a five-dimensional system.

(3) e_9

e_9 IT; information storage

(4) e_{10}

e_{10} IF; information flow

The following system expresses the key elements of information processing:

$$IW - S - U - \begin{matrix} IS \\ IC \\ IP \\ SGM \end{matrix} EI - IT - IF$$

The significant kinetic features of the interaction mechanism are as follows:

The interaction (I) is the set of transformation. The synergetic effect provides the rule for forming new forms in terms of interaction. The statements indicating initial forms of the objects are described in the expressions of (3.2) and (3.3).

Set the objects, i.e., IF in the system as, $E^{(1)}, E^{(2)}, \ldots, E^{(m)}$, products of interaction as $C^{(1)}, C^{(2)}, \ldots, C^{(n)}$, a_{ij} as coefficients of $E^{(i)}$ in $C^{(i)}$, then

$$C^{(1)} = E^{(1)}_{a11} E^{(2)}_{a12} \ldots\ldots E^{(m)}_{a1m} ,$$

$$C^{(2)} = E^{(1)}_{a21} E^{(2)}_{a22} \ldots\ldots E^{(m)}_{a2m} ,$$

$$\ldots\ldots\ldots\ldots\ldots\ldots$$

$$C^{(n)} = E^{(1)}_{an1} E^{(2)}_{an2} \ldots\ldots E^{(m)}_{anm} .$$

Set b_j $(j=1,2,\ldots,m)$ as coefficients of $E^{(i)}$, and x_i $(i=1,2,\ldots,n)$ as coefficients of $C^{(i)}$ in the interaction, then,

$$
\begin{array}{c}
b_1 E^{(1)} + b_2 E^{(2)} + \ldots\ldots + b_m E^{(m)} \\
\downarrow \\
x_1 C^{(1)} + x_2 C^{(2)} + \ldots\ldots + x_n C^{(n)} .
\end{array}
$$

In the system,

$f_i(x_i)$ = free energy of the products of interaction

$f_i(x_i) \in [0,1]$

The free energy of the system is,

$$\phi(x_1, x_2, \ldots, x_n) = f_1(x_1, x_2, \ldots, x_n) + \ldots + f_n(x_1, x_2, \ldots, x_n) \tag{3.1}$$

$\phi(x_1, x_2, \ldots, x_n) \in [0,1]$

x_i is nonnegative,

$$x_i \geqslant 0, \quad i=1,2,\ldots,n, \tag{3.2}$$

assume conservative law exists,

$$\sum_{i=1}^{n} a_{ij} x_i = b_j , \quad j=1,2,\ldots,m \tag{3.3}$$

H is denoted as a higher order substance, which can be obtained in terms of the following formula:

$$H = C^{(i)} - \sum_{i=0}^{m} \underset{\sim}{E}^{(i)} + \underline{\Delta x}\ , \qquad (3.4)$$

$\underset{\sim}{E}^{(i)}$ is denoted as $E^{(i)}$ which loses part-whole relations, and Δx is the fuzziness of $E^{(i)}$ without losing part-whole relations. The general problem can be summarized as, an optimal solution: find the minimum of $(x_1, x_2, \ldots, x_n)$ that satisfies the conditions of (3.2) and (3.3); a quasi-optimal solution: find the quasi-optimal solution.

For a one dimensional system, in which x is the input, y is the output, the differential equation for describing systems characteristics is as follows:

$$y^{(n)} + a_1 y^{(n-1)} + a_2 y^{(n-2)} + \ldots + a_{n-1} y^{(1)} + a_n y$$

$$= b_0 x^{(m)} + b_1 x^{(m-1)} + \ldots + b_{m-1} x^{(1)} + b_m x \qquad (3.5)$$

For the interaction processes, the corresponding differential equations must include all known and unknown variables. However, because of the tremendous number of factors, it is extremely difficult to list all variables and to solve all of these equations. $E^{(i)}$ tends to move in a complex manner throughout the interaction process. Every $E^{(i)}$ at any specific time is in a stochastic state.

In fact, we are not interested in the motion of individual $E^{(i)}$; more important is the general state derived from general interaction which involves all relevant $E^{(i)}$.

In accordance with interaction, it is possible to generate a wide range of possible products symbolically represented by free energy. Therefore, one can express the system in terms of this symbolism.

The instantaneous characteristics can be depicted approximately. Assume free energy as a symbolism, then, set $X = \{x_1, x_2, \ldots, x_n\}$, $Y = \{y_1, y_2, \ldots, y_m\}$, $0 \leqslant L \leqslant 1$.

Theorem 3.1: Set $R = (r_{ij})_{n \times n}$, $R = \bigvee_{p=1}^{n} R^{p}$.

Theorem 3.2: Set $R = (r_{ij})_{n \times n}$ satisfies self-reciprocity and symmetry, then

$$R = R^{n-1}.$$

In a fuzzy matrix,

$$R = \begin{bmatrix} r_{11} & r_{12} & \ldots & r_{1m} \\ \ldots & \ldots & \ldots & \ldots \\ r_{n1} & r_{n2} & \ldots & r_{nm} \end{bmatrix},$$

$r_{ij} = R(x_i, y_j)$, $i \leqslant n$, $j \leqslant m$. Specically, R: $X \times Y \rightarrow [0,1]$, it belongs to F matrix [46].

The general form of the fuzzy matrix is,

$$A = \begin{bmatrix} a_{11} & a_{12} \ldots & a_{1n} \\ a_{21} & a_{22} \ldots & a_{2n} \\ \ldots & \ldots & \ldots \\ a_{m1} & a_{m2} & a_{mn} \end{bmatrix},$$

in which, $0 \leqslant a_{ij} \leqslant 1$, $1 \leqslant i \leqslant m$, $1 \leqslant j \leqslant n$, $A=[a_{ij}]$.

For $A=[a_{ij}]$, $B=[b_{ij}]$, if

$$C_{ij} = \max [a_{ij}, b_{ij}] = a_{ij} \vee b_{ij},$$

then $C=[c_{ij}]$ equals $C=A \vee B$.

For $A=[a_{ij}]$, $B=[b_{ij}]$, if

$$C_{ij} = \min [a_{ij}, b_{ij}] = a_{ij} \wedge b_{ij},$$

then $C=[c_{ij}]$ equals $C=A \wedge B$.

Finally,

$$C_{ij} = \max_k \min [a_{ik}, b_{kj}] = \vee_k [a_{ik} \wedge b_{kj}]$$

Definition 3.1: Set $R = (r_{ij})$, for any $\lambda \in [0,1]$,

$$R_\lambda = ({}_\lambda r_{ij})$$

then,

$$r_{ij} = \begin{cases} 1 & \text{if } r_{ij} \geqslant \lambda \\ 0 & \text{if } r_{ij} < \lambda , \end{cases}$$

$R_\lambda = ({}_\lambda r_{ij})$ is called λ-cut matrix of R, and defined by

1. $(A \vee B)\lambda = A\lambda \vee B\lambda$.

2. $(A \wedge B)\lambda = A\lambda \wedge B\lambda$.

3. If λ, $\mu \varepsilon [0,1]$, $\lambda < \mu$, then $A\lambda \supseteq A\mu$.

The useful insight is that the analyst can know the extent of free energy in $C^{(n)}$ in relation to quasi-optimal solution.

The process of interaction can be expressed approximately in terms of fuzzy control systems, as Figure 1 shows. The fuzzy conditional statements can be described as,

if $E^{(i)}$ and $E^{(i)}$ then $C^{(i)}$,
if $E^{(i)}$ and $E^{(i)}$ then $C^{(i)}$,

........................;
if $E^{(i)}$ and $E^{(i)}$ then $C^{(i)}$.

For every statement, the fuzzy relation is as follows,

R_1, R_2,......, R_p,

the R for the system is,

$$R = R_1 \vee R_2 \vee \ldots\ldots \vee R_p = \bigvee_{i=1}^{p} R_i \quad .$$

Suppose A and B are inputs, C is output, and $D = A \times B$,

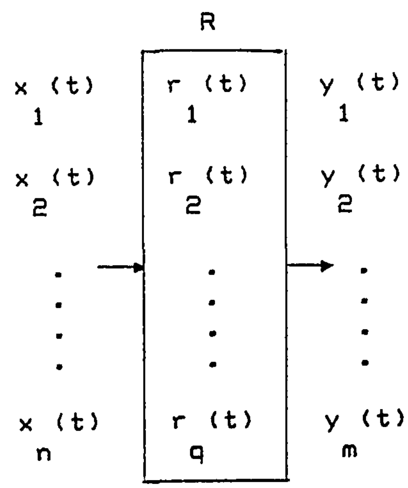
then,

$$R = D^T \times C \ .$$

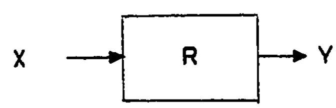
Suppose A is input, B is output. If A_1 is known, $B_1 = A_1 \times R$, $R = A \times B$.

It must be acknowledged that the necessary framework of concepts for this highly complicated nonlinear process is still under development. Although we are deeply and inescapably aware of the vast range of unexploited details, we must not allow such preoccupations to obscure our approximate understanding of the generalized mechanism operated by decisionmaking in a synergetic interaction. The notion of mechanism here does not simply mean the dimensionality, but actually embraces the structures of affectors and effectors.

The model is a generalization; the form is a special case. This study's interest is to introduce the general structure of a multidimensional process and suggest its implications for the system synthesis of economic systems analysis. Since one cannot construct a program of all programs, for a specific system, the task is to single out systems factors as relevant to the problem



(a) multidimensional systems



(b) one-dimensional system

Figure 1. Fuzzy Control Systems

under consideration, to approximate the significant relationships among these factors, and to formulate hypotheses regarding the interaction process.

3.2.2. Order Parameter, Critical Point, And Phase Transition

Multidimensional analysis further consists of both multidimensional perspectives and interaction system. In the interaction system, a variety of perspectives is in relative motion and moves into an orderly image of the events concerned. The event tends to bring order out of perspectives, and results from the change of interrelationships.

No subsystem is immune to substitution; in another word, no aspect of a system is precluded from kinetics. The order parameters are the long-lived systems that prevail over the short-lived ones, i.e., certain states of order grow continuously until they eventually supplant all other parts of of a system. A higher order state is both the cause and effect of substitution. A system displays a higher order state that may hold over a relatively short run. Over the long run, the relationships are altered by the structural effects. The implication is that the perspective from which a system is viewed depends on particular circumstances at the time. It is possible to predict the new states of order in a well-structured system, but is extremely difficult to do so in a purely ill-structured system. In an ill-structured system, the Markov transition matrix may not be apparent because the matrix is not time-invariant. Having passed the critical point, the transition matrix may be revealed in some cases. However, in some other cases, the solutions to the various equations may, at a particular critical point, offer more than one possible solution [47]. There might be, in a complicated system far from equilibrium, a whole series of bifurcations, as long as the transition matrix is random. In this system, the list of variables in the state vector may not be constant; new variables may emerge, old ones disappear; and the transition probabilities may alter from time to time, causing some transitional probabilities to fall to zero, and others to become non-zero, but with no change in the elements in the state vector. The establishment of the states also depends on random events, and without them the new state would not be finally determined. The same set of interaction may lead to different orders under different randomness. Rempfer [17] has proved this hypothesis mathematically.

Possibly a complicated fluctuation determines the final choice between equivalent states of order. Numerous phenomena present a certain instability because initial symmetry disappears. In the process of transformation, a substituent may arise from fluctuation in the systems' structure. Then, a higher order state is established.

A system can be governed not only by one but by several order parameters. Three order parameters can be represented by perspectives that include an equilateral triangle. In the phase of chaotic motion of three objects, three order parameters enter into an interaction, thereby undulating the system to and fro among its various states of motion. For a certain time, one order parameter prevails over the two others. After a short while, however, it may lose its dominant position to another order parameter, and the sequence is repeated. Sometimes the perspectives are in conflict, sometimes they cooperate, or shift from conflict to cooperation. This change of domination is totally irregular. Chaotic motion might lead to the assumption that the order parameters have lost their power to control. The macroproperty of the multidimensional system can be described either by cooperation or by substitution among equivalent forces, creating a new pattern.

A well-ordered structure can be created from chaos and maintained with a constant supply of energy and information. The cooperation of subsystems can result in order. The overall context is sustained by the order parameters, which become most significant whenever the macrostructure of the system changes.

In project evaluation, the decisionmaker should look squarely at multidimensional system and its order parameter.

A concrete example helps show that in most cases the decision is not based on economic criteria, but on systems characteristics related to the formation of order parameters.

In the Himalayas of Tibet near the border between India and China exists perhaps the world's greatest potential hydroelectric resource. A major river--the Tsangpo-Brahmaputra--drops 10,000 feet between two points only forty miles apart. A tunnel connecting the upper river (Tsangpo) with the lower river (Brahmaputra) could provide enough hydroelectric power to meet a significant portion of the energy needs of Tibet, India, and Bandladesh. In addition to being an important renewable energy source, such a dam could partially control the catastrophic floods that now ravage Bangladesh. The project would, however, require close political and economic cooperation between China and India, since the dam would have to be in Tibet, whereas the generating plant would be across the border in India. Due to the order parameter, i.e., the political instability in southern Asia, at present, the dam will not be built.

The totality of all possible states is described as the phase space of the system. The phase transition, an inevitable element of irrationality, means a transition from disorder to order or vice versa [1]. In disorderly state, the multidimensional system, which can point in all directions, is in a symmetrical state, with no dominant direction. However, having entered the interaction step, directions are selected and the original symmetry of the directions ends. The different phases result from the substitution effect among different perspectives, the substitutive behavior of collective type of motion. This motion plays an important role in forming an order parameter, as previously described, directing the motion of the subsystems. Once such motion has been established in subsystems, some subsystems may be suppressed by the order parameters.

When the state of motion is unstable, even a very minor fluctuation often affects the phase transition. Whenever a new state of order begins, nature again leaves the system a choice of several possibilities. At the point of instability, the system tests new possibilities of an orderly macrostate; the new collective form of motion will progressingly become energetic, and finally gain superiority over all others. Once the choice has been made, all subsystems accept it.

The collective motion is complicated. Instability may shift from the subsystem to the system or from the system to the subsystem. This interrelation between the subsystem and system may result in the subsystem being deprived of its freedom that may produce instability according to systems measure. In other words, a great deal of freedom for the subsystem means an increasing possibility of conflict in the system, as the proposed interaction model shows.

3.2.3. Decision-Prone Area--Boundary

Decisionmaking is associated with the perspectives' interactions at the phase boundaries, and a significant fraction of any decision occurs at such boundaries. The substitutional driving mechanism provides a general framework for understanding the pattern of decisionmaking on the border.

Decisionmaking is associated with displacements on the borders, which occur when the stress across the border builds up to a sufficient level to cause transition. When a border is in a coherent state, elastic energy accumulates in the perspectives around the border. When stress reaches a critical value, the border slips and a transition is made. The elastic energy stored in the adjacent perspectives partially dissipates on the border and partially radiates away as energy. The relative motions of the perspectives are often accommodated on major borders.

3.2.4. Energy And Information

Within a multidimensional system, flows of energy result in flows of information. The transition of interactions (energy) in an orderly structure forms the information, which can be recognized in terms of macroscopic hierarchical structures.

The basic mechanism of decisionmaking provides the energy. A sufficient energy must be supplied to produce a positive substitute rate. By using an energy function, the stability of the system can be determined, as well as the causes of instability. At a certain level of energy supply and interaction, the perspectives appear and disappear, and macro-changes of the system take place.

In order to understand the energy in decisionmaking process, it is essential to introduce the concept of stress and strain distribution. The creep on the boundary, in response to forces, leads to fuzzy, fluid-like behavior in the elements on the border. The fluid-like behavior of decisionmaking is thus explained by the creep process. In many cases, the final decisionmaking can be attributed to substitutional activated creep processes. The creep relaxes elastic stress, and the pressure solution creep can account for the decisionmaking. The process involves the dissolution of elements in regions of high pressure and their precipitation in regions of low pressure. At low stress levels, the dominant creep process exists. The diffusion relieves an applied stress and results in strain. At first, the elastic behavior of a perspective arises from the internal forces that maintain each element in its position, resisting any attempt to move elements further apart or closer together. If the perspectives are compressed, the internal force resists the compression. The strain rate is proportional to the stress. At a higher stress level, the creep results from the movement of dislocations through the multidimensional system. In the process of deformation, an elastic element will exhibit linear, elastic behavior until a yield stress is reached. The element can then be deformed plastically at this stress. The multidimensional system can be deformed, and result in folding. Strain or deformation at the surface of the system often stems from perspective substitution motion. Thus, the measurement of surface strain can provide important information on the dynamic process of decision-making.

Obviously, if deformation occurs on boundary, high stress levels can be expected. The interaction of perspectives is an important source of stress. The state of stress results from all relevant contributions. Although there is no comprehensive understanding of the motion, most likely decisionmaking is the result of complex interactions among perspectives, and the multiplicity of perspectives can deform the entire process. Therefore, the driving mechanism provides an approximate framework for understanding the orientation of decisionmaking.

3.2.5. Systems Dynamics

Making an economic systems decision is a dynamic process of perspective interactions. However, the structure of a decision system used to be regarded as static. We ought to be aware that a decision directed against one perspective is not based on a certain perspective against another. It is the certain collective modes of behavior that lead to a certain result. System behavior exists when subsystems act as if by prearrangment. Actually, every subsystem is in relative motion. Any equilibrium is subject to dynamic processes rather than artificial intentions. In the language of autopoiesis, the interaction gives rise to the system structure in a self-organizing form. Structures form, substitute, coexist, or result in higher order structures, powered by spontaneous forces.

3.2.6. Three-Dimensional System

Multiple forces, exerted on the analytical, external, and internal aspects of decisionmaking, confront almost all economic systems issues. These pressures result in stresses, which are inherent in the increased complexity of the issue and the increased scale of the systems.

Three Dimensional Stress

Here we provide a quantitative model of the different types of collision, in terms of the relative magnitude of the principal stresses, assuming that the stress in x, y, and z directions are the principal stresses. In three dimensions, there are nine components of stress: include S_{xx}, S_{yy}, and S_{zz}, normal stresses; and S_{xy}, S_{yx}, S_{xz},

S_{zx}, S_{yz}, and S_{zy}, shear stresses. Supposing that the parallelepiped is not to rotate about any of its axes, then $S_{xy} = S_{yx}$, $S_{xz} = S_{zx}$, and $S_{yz} = S_{zy}$, and six of the stress components are independent. In the principal axes, three orthogonal axes can be expressed, with the result that all shear stresses equal zero. By convention, they are maximum principal stress, intermediate principal stress and minimum principal stress. The six independent stresses, the orientation of the principal axes and the values of the principal stresses provide information about the state of stress at a point.

In the perspective cooperation case, the three principal stresses are equal, identified as $S_1 = S_2 = S_3$. When the three principal stresses are inequal, the pressure is defined as their means. The pressure is invariant to the choice of coordinate system. It is equal to the mean of the normal stresses in any coordinate system, such as

$$p = 1/3\ (S_{xx} + S_{yy} + S_{zz}).$$

Triple Perspectives Intersection

In accordance with interaction theory, a perspective always ends by intersecting another perspective. Three perspectives result in an intersection as a triple intersection. In principle, there are numerous triple intersections, though some cannot, in fact, exist. The required condition for the existence of a triple intersection is that the three vector velocities defining relative motions between perspective pairs at a triple intersection must form a closed triangle. For many types of triple junctions this condition requires a particular orientation of the perspective boundary. Assuming P represents a perspective, the velocity condition for all triple intersections requires that,

$$P_1 + P_2 + P_3 = 0 .$$

The purpose of describing the mathematical aspects of a decisionmaking process is to explain the dynamic process of decisionmaking. Detailed mathematical analysis of the decisionmaking process is not the major purpose of this study.

3.3. The Implications To Systems Design In Economic Systems Analysis

3.3.1. Systems Analysis And Purposeful Formulation

Multidimensional perspectives are an inexhaustible source of mystery to us through the abundance of their patterns and the delicacy of their structures in which the subsystems interact with each other. Interest is increasingly turning to the questions of how these structures originate and what mechanisms are at work. The expression of dimensionality has basically answered the first question. The second are partially answered by the basic mechanisms discussed in this chapter and by omnidimensional structures to be explored in the future research of the decisionmaking process.

Figure 2 shows the hierarchical structure of economic systems analysis. In this analysis, the multidimensional system consists of the diverse subsystems. In systematic methodology, significant effort should be devoted to systems design, including the understanding of the interactions among multidimensional perspectives and the determination of purposeful alternatives. The analysis points to the degree of motion in systems between the purposes of subsystems, systems, and wider systems. The conventional method tends to overlook such motion, believing that the analysts can ascertain the real objectives. All perspectives, from a single perspective to the multidimensional system, interact in a complex manner. The subsystems that engage each other directly or indirectly make the system complex. The collective behavior of subsystems directly determines the state through substitution or cooperation. A final outcome will be formed depending on relative motion, critical point, higher order states, and systems structure. This picture of objects becomes a picture of structures and orders, subject to a bistochastic process. Every construction seems to make sense, as it provides an autopoietic view. The most important implications for

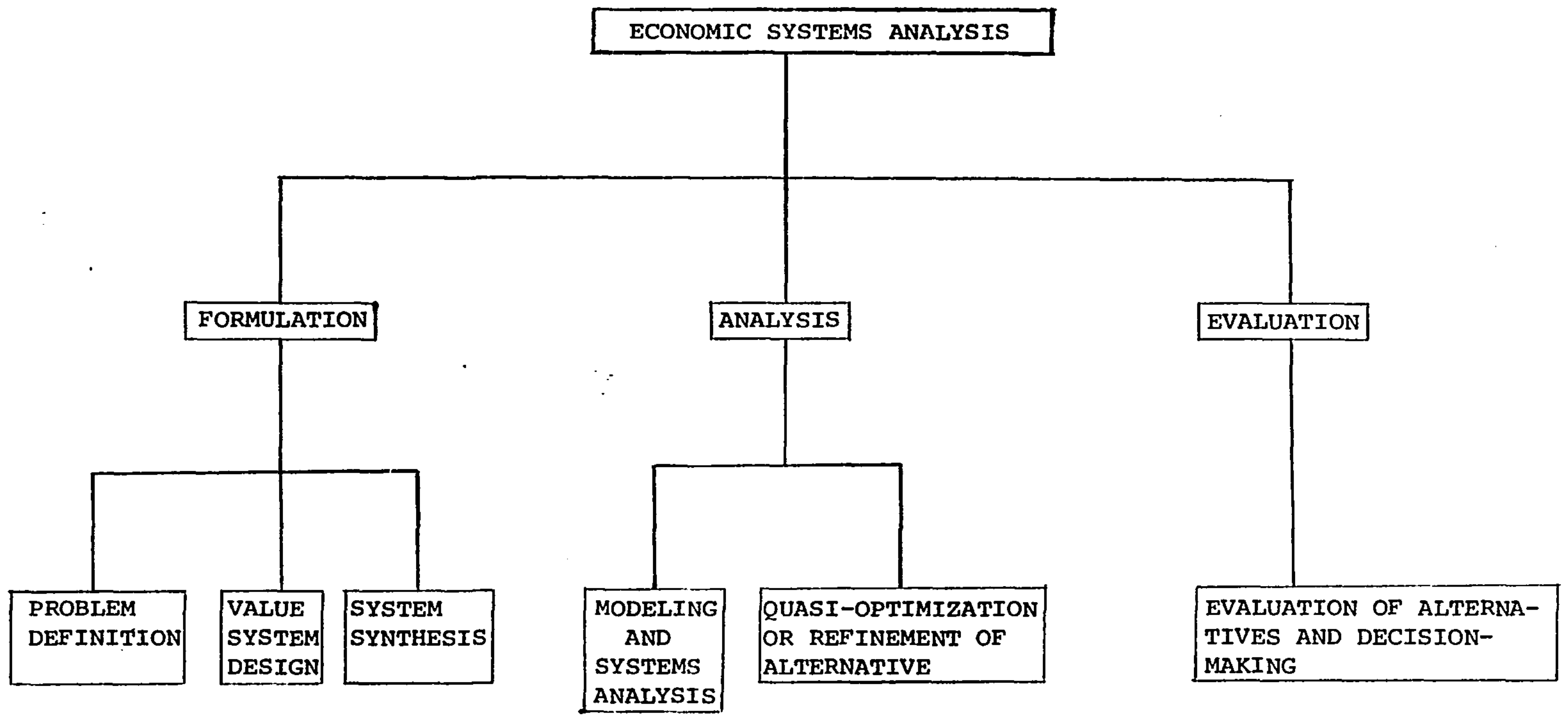


FIGURE 2. HIERARCHICAL STRUCTURE OF ECONOMIC SYSTEMS ANALYSIS

economic systems analysis are that:

1. The elements in the designed system are considered and evaluated as related to the purpose of systems.

2. The system is self-regulating through the dynamic interactions among subsystems.

3. The system is autopoietic and spontaneous, i.e., (a). a higher order structure must result in its specific function, and it is represented by high order substance H, and (b). the motion of subsystems is reversible while the motion of systems is irreversible.

4. The existence of an interaction between a growing understanding of what is involved with what is known at the start.

Therefore, constant redefinition is essential and relatively less effort is needed for the optimization effort. This step constitutes one of the main watersheds between conventional methodology and systems methodology [36, 48, 49, 50, 51, 52, 53, 54, 55]. An H-type merger of multidimensional perspectives of real-world concerns increases the probability of posing the right problem in terms of a systematic view and significantly improves the likelihood of implementation. The systems process is supposed to encompass multidimensional perspectives, and synthesize them into an H-type system.

This view of synergetic multidimensional decision systems was shared by Heisenberg [1, p.205] to some extent:

> ... Remembering our experience in modern physics it is easy to see that there must always be a fundamental complementarity between deliberation and decision. In the practical decisions of life it will scarcely ever be possible to go through all the arguments in favor of or against one possible decision, and one will therefore always have to act on insufficient evidence. The decision finally takes place by pushing away all the arguments-both those that have been understood and others that might come up through further deliberation-and by cutting off all pondering. The decision may be the result of deliberation, but it is at the same time complementary to deliberation; it excludes deliberation. Even the most important decisions in life must always contain this inevitable element of irrationality.

3.3.2. Controlled Feedback And Iterative Design

An important implication of the foregoing analysis is that the errors associated with the data and modeling process, such as computative illusory, time and angle distortions of perspectives, and deceptive sensing of information, create a need in the synthesizing system to send feedback to the previous steps. This points to the need to search for alternatives which might fill in missing parts of the system. The formulation process may not even be fulfilled because the information space (see interaction model) is too limited to hold the information necessary to perceive the structure of the system. This function, self-adjusting through the availability of feedback, is an important part of the view suggested in Chapter 2. We have a system: $y=cx+w$, y is the measured output, c is a constant, x is the part of the state we want to regulate, and w is the noise. The purpose is to insulate the output y from w.

CHAPTER 4

FUZZY MULTIOBJECTIVE PROGRAMMING AND MARKOV COMMUNICATION THEORY IN ECONOMIC SYSTEMS ANALYSIS

Never aim at more precision than is required by the problem in hand.

K. Popper [19, p.7]

4.1. Introduction

4.1.1. Resolution Level

Analyzing an economic system characterized by multidimensionality involves two levels of description: one an analysis of the multidimensional system, and the other a discussion of its behavior in terms of macrostructure. After the multidimensional analysis, the resolution level is reached. The fuzzy objective reformulation for the system and its sub-systems cannot be established until complexities have been scrutinized. At this level, a quasi-quantitative description of the interacting perspectives becomes possible. We can again choose between either a classical mathematical framework or a fuzzy framework. In this study, imprecision is dealt with from a fuzzy mathematical point of view, representing a step toward rapprochement between the precision of classical mathematics and the pervasive imprecision of economic systems analysis.

4.1.2. Singerian Multiobjective Analysis Vs. Marglin's Multiobjective Analysis

The analysis of multiobjective problems has evolved rapidly over the last three decades. The economists' first concern that could be characterized as multiobjective was the efficient allocation of resources. In 1962, Marglin [16] introduced multiobjective analysis as an alternative to conventional economic systems analysis, using a method founded on the Newtonian-Kantian system.

Multiobjective analysis closely relates to the proposed philosophical paradigm and the fuzzy resolution level of multidimensional structure. Therefore, the appropriate multiobjective analysis is a Singerian analysis that encompasses all modes of inquiry to the extent they prove useful.

In response to the appeal made by Pierskalla, Mintzberg, Sage, and Luft [35, 56, 57, 58] for searching an appropriate analytical method for ill-structured systems, a practical, interactive, and iterative fuzzy programming method for solving a quasi-optimization problem under constraints involving a multiple objective function is proposed; its basic characteristic has been discussed in Chapter 2. The principal aim is to search for a quasi-optimization, and reproduce the real decisionmaking process.

The algorithm begins with a fuzzy formulation in the steps of systems synthesis and analysis. Then, learning by trial and error is initiated, which comprises learning from systematic observation as well as from chance observation. In the process of analysis, a fuzzified preferred solution becomes the current solution, and, based on that, a new search starts. Then, another fuzzified preferred solution replaces the current solution. This is a repetitive process, the search continuing until no improvement can be found. Most solutions will fall within the efficient boundary, though since the boundaries are fuzzified, the solutions may be moved on or beyond the efficient boundary of the feasible region. In the case of an efficient solution within the feasible region, various alternatives among the current solutions are tested in order to choose a solution that is, momentarily, preferable to the current one.

4.1.3. Characteristics Of Adaptation

The proposed adaptive economic systems analysis is a study of economic systems analysis incorporating an adapted space produced by flows of energy and information. An adaptive system's structure can be adjusted so that its performance improves through contact with its environment. The adaptation can begin with a division of reality into two parts, one representing the behavior of a part of the system, i.e., the decisionmaker, the other representing the parts of wider systems, i.e., system. The adaptive economic systems analysis is a collection of perspectives that react and adapt to each other and to the system. In such a system, both reaction and adaptation occur throughout. The linkage communicates information among the system and subsystems. Emphasizing the perspective adaptation creates a practical way of thinking which allows decisionmakers to respond to the system and modify their behavior. Interaction allows the changing of actions from one mode to another in accordance with the systems state. The decisionmaker survives only if he generates an admissible decision under a certain system.

The elemental decomposition of an adaptive decisionmaker is into two constituent parts, that which receives and processes information about the system and that which responds reactively. It has a similar structure to that of a servomechanism. The first subsystem's function may be broken down into observation, measurement, processing, and storage (see interaction model). The second's function is into adaptive reaction. This distinction recognizes that a socio-economic system can be realized comprehensively only with great difficulty, and that the decisionmaker must therefore adapt to the system.

Adaptation is fuzzy by nature. In a two-valued logic system, the adaptation seems mechanical, but actually, the adaptation exhibits an extremely broad range of fuzzy behavior. Adaptive decisionmaking can be described by a vector of characteristic variables, the values of which must lie in a fuzzy set to ensure the acceptability of the resulting decision. The value of each characteristic variable is determined by the systems state and the decisionmaker's decision. The search for rules of analytical adaptation that exhibit homeostasis appears to be necessary.

4.2. Truthfulness, Randomness, And Fuzziness

At the outset of systems analysis, in the 1940s, systems analysts accepted that there could be no absolutely accurate measurement. Complex relationships, plus the instability of precise logic in dealing with the vagueness inherent in economic systems analysis, made it difficult to define clear borders. In economic systems analysis, the varieties of complexity do not lead to easily analyzable models; hence, the essence of conventional methodology is to treat what is vague as if it were precise. Even for pure economic evaluation of alternatives, true complexity arises when simple systems are combined into numerous, complex assemblages. In systems analysis, system theory is, in fact, fuzzy systems theory with distinguishing characteristics for dealing with key aspects of the humanistic system [59]. In order to achieve a meaningful representation we have to compromise on exactness.

The human perception of reality is ambiguous. In most cases, a decisionmaker is assumed to choose a value between two-valued logic representations in accordance with momentary judgment. Referring to the decisionmaker's picture of the system as fuzzy means that though his description of a system's structure is likely to be exact, his estimate of parameters, constraints or even the system itself is ambiguous. The eigenvalue links limited inputs with those imprinted in mind. A decisionmaker may make a sequence of choices inconsistent with fixed functions.

In economic systems analysis, solutions are rarely clear-cut; usually, several similar ones often exist. These alternatives are intimately connected with the interlinked modes of a fuzzy system. Having decided upon the objectives, and accepting that different alternatives will achieve the various objectives to differing degrees, we may then explore the degree of approximation appropriate to the economic systems issue by using fuzzy linguistic variables that result from decisionmakers' reliance on judgment, intuition, and experience. One way to handle subjective assessment of the attainment of the objective is to assign a fuzzy membership function to each alternative to represent the best estimates as to its range of effectiveness in attaining the objective under consideration. Heisenberg

[1, p.201] indicated that,

> We know that any understanding must be based finally upon the natural language because it is only there that we can be certain to touch reality, and hence we must be skeptical about any skepticism with regard to this natural language and its essential concepts.

The lack of precise data from which the measures of the systems can be developed, and the lack of an adequate method from which the imprecise measure can be approached, support the application of Markov communication theory and fuzzy sets theory in the following ways:

Classification of costs and benefits. Due to complexity, it is hard to classify every effect as being either a cost or a benefit. In military economic systems analysis, many costs measured in dollars or human lives are actually estimates made on a speculative basis [31].

Distributional effects. There is no exact way to represent or explain distributional effects.

Measurement. Measures can be partially quantitatively determined and partially judgmental. The description of side-effects, externalities, social cost, social interest, future cost, noncommensurate units, and higher order effects are highly qualitative rather than quantitative, and no market price is available. Judgment and speculation guide the analyst more than economic calculations. Analysts tend to dismiss costs that cannot be measured quantitatively as non-cost considerations or qualitative factors. In sum, all costs and benefits measurements are approximations.

Multiple objectives. Numerous examples of multiobjective trade-offs are available in the literature [20, 21, 22, 27, 30, 60]. In the public sector, objectives are seldom entirely agreed upon, and tend instead to be stated in broad, imprecise terms. Public policy objectives are typically ill-structured, multiple, conflicting, vague, approximate, and noncommensurate. Optimization is never the real aim.

Ranking. Due to limited cognitive capability, and the imperfect information about the possible states of nature and transition probability, it may not be possible for both analysts and decisionmakers to prepare an unambiguous ranking of all alternatives.

Strategic bias. Anticipation of a contracting agent's willingness to pay for a study may lead to an attempt to influence the outcome or result by responding untruthfully.

Information bias. This further imprecision results from the respondent's lack of complete information for willingness to pay.

In sum, the conventional technique is rigid in the sense that it demands precise data and functional relationships of the problem. In practice, however, we rarely have precise measurements. In short, science = truthfulness + randomness + fuzziness. The alternative is to consider Markov communication theory and fuzzy sets theory. A fuzzy formulation would consider the imprecise objectives and constraints. By focusing on this imprecision, approximation can be introduced into the system, and an adaptive progression achieved.

In the analysis, the role played by analysts includes:

1. Helping the decisionmaker to develop all of the relevant objectives during the multidimensional analysis by recognizing synergetic effects.

2. Searching for the possible ways to attain these approximate objectives during the search process.

4.3. Introduction To Fuzzy Systems Theory

4.3.1. Markov Communication Theory And Its Significance To Ill-Structured Systems

The basic axioms about propositions in symbolic logic are that,

1. A statement is either true or false;

2. A statement cannot be simultaneously true and false.

This absolute mode of thought has long existed. However, it has been found that the imprecise concepts lead to contradictions in a two-valued logic. Russell indicated that not all propositional truth can be organized by the theory of truth functions. Russell's Paradox, Cantor's Well-Ordering Principle, and Zermelo's Axiom of Choice all challenged the reliance on two-valued logic as a basis for inquiry. As another school of thought, the term "fuzzy" was introduced in 1962 by Zadeh in a paper about the transition from circuit theory to systems theory in which he called for a "mathematics of fuzzy or cloudy quantities which are not described in terms of probability distribution" [61, p.856]. This paper was followed in 1965 by the proposing of an imprecise mathematics termed as fuzzy sets theory [62].

In fuzzy sets theory, let X be a classical set of objects, called the universe, whose generic elements are denoted x. Membership in a classical subset A of X is often viewed as a characteristic function u_A from X to [0,1]. Bellman and Zadeh [63, p.B141] give an abstract classification of imprecision in terms of "classes in which there is no sharp transition from membership to non-membership." Rempfer defined an F-set as a function u(x) with value $0 \leq u(x) \leq 1$ for each x. The power of an F-set is $\sum u(x) = v$. A special case: the F-sets $u_i(x)$, $i \in 1,2, \ldots, r$ are said to be a partition if $\sum_i u_i(x)=1$ for each x. Rempfer illustrates that "partition-conserving mappings belong to the class of Markov chains. To be partition-conserving, they are necessarily bistochastic Markov chains" [17, p.1]. As indicated in previous chapters, a stochastical process is the major characteristic of an ill-structured system. Rempfer's definition makes it possible to propose a stochastical process in an ill-structured system using a mathematical proof. The Markov communication process explains fuzzy behavior in an ill-structured system more completely than any other definitions, as does the process explain the interchange between membership and nonmembership instead of setting a real number subjectively as a characteristic function. Note that in many practical situations, there is both randomness and fuzziness. In short, the crucial difference between Rempfer's Markov communication theory and Zadeh's fuzzy sets theory lie in the definition of a decision system at a moment of time: Rempfer introduces the concept of probability into the definition of state, while Zadeh does not.

For mathematical programming, there will be many promising applications of Markov process, such as in constructing an optimal input model for C, A, and B in,

$$\begin{aligned} &\text{Optimize} \quad CX \\ &\text{s.t.} \quad AX \leqslant B \\ &\qquad\quad X \geqslant 0 \end{aligned} \tag{4.1}$$

when coefficients are ill-defined. In terms of Markov communication theory, mathematical programming is considered an input-output system, the input is data, and the output is the feasible set--the set of probable values. The model has the property that the perturbation of input results in an optimal value function. In the input optimization, we first optimize input, and then the mathematical programming. When output is a continuous function of input, the optimal realization of mathematical programming is achieved.

To demonstrate the potential for improving mathematical programs, we begin with a mathematical model (P,K) in terms of Markov process and then find their optimal realizations using input optimization. To this end we consider a linear program of the form,

$$
\begin{aligned}
(P,K) \qquad & \text{Optimize } f(CX,\ CK) \\
& \quad \text{s.t. } f(AX,\ AK) \leqslant f(B,BK) \\
& \qquad K \varepsilon I \\
& \qquad L \leqslant k \leqslant U \qquad\qquad (4.2)
\end{aligned}
$$

Here $K=\{k_i\}_n \varepsilon R^p$ is a data or parameter vector and $X = \{x_i\} \varepsilon R^n$ is the vector variable. $R^n \times R^p \to R$ are continuous functions. K is bounded, where $I \varepsilon R$ is some specified set. L and U are lower and upper bounds respectively. In the optimization of an engineering project, the component k_i may represent a transition of states, such as capacities of resources. Now assume that by increasing additional units of energy and improving efficiency of the system we, in fact, increase the cost, however, by choosing optimal parameters, the cost can be decreased below the original level. The components of X may be interpreted as the level of the system, such as the economic efficiency and environmental impacts. For each choice of $k \varepsilon I$, the model determines a feasible set F(k), the probable value f(k), and the set of optimal solutions {x| b(k)}. Therefore, we may think of this as an input-output system, with the input k and the output: $F(k)$, $f(k)$, $\{x|$ $b(k)\}$. The problem (P,K) is an input optimization model.

The crucial step in the design of a problem which is to be solved by fuzzy sets methods is to determine the membership functions of the sets. An important question is how, and from what kind of data can membership functions actually be derived? Most analysts recognize that determining the membership functions is vital in a practical application of fuzzy sets theory, but the problem has not been systematically studied in the literature [46]. The methods used in the past have often been heuristically based. Rempfer proposes a theory which offers a more rigorous method of defining statistically-based membership functions. This result forms a firmer theoretical ground for a class of membership functions which has been previously proposed.

This study explores the application of the Rempfer theory in deriving a membership function, i.e., the problem of identifying an input $k^* \in I$, which optimizes the optimal value function f over the set I. Such a random optimal input determines the optimal value $f(k^*)$. If k^* is an optimal input obtained by a Markov analysis of K, the (P,K^*) is an optimal realization of (P,K). Clearly, the value of the program (P,K^*) can only improve the value of (P,K). Therefore, the random optimal input k^* can be regarded as a most probable function in formulation instead of subjective fuzzy linguistic approximation.

If the fuzziness of coefficients is decreased by using information about the coefficients, we can expect a more realistic solution than could be obtained without information: the less the fuzziness of coefficients becomes, the more realistic is the solution obtained. Basically, in input random optimization, we randomly optimize the model. We assume that the model is convex. The procedure for random input consists of, a. analysis of the existing input k and its regions of stability, and b. analysis of the random optimal input k*, i.e., determination of a random optimal value in accordance with Rempfer theory. The main objective is, by reducing fuzziness, to get a less fuzzy objective function, and convert fuzzy constraints into less fuzzy ones. We can expect to obtain a more satisfactory solution than without conversion.

By using the property of a doubly stochastic matrix, a simulated Markov process can be represented. Assume a Markov chain $\{Z_n\}$ is homogeneous, with transition probability $P = (P_{ij})$, $i,j=0,1,2,\ldots$, and with initial distribution $\{p_i\}$, $i=0,1,2,\ldots$. Set Z as a discrete random variable: $P\{Z=a_i\}=p_i$, in which $p_i \geqslant 0 \leqslant 1$, $\Sigma_i\, p_i=1$. Then we create random samples on the computer with $x_1, x_2, x_3, \ldots$, being uniformly, randomly deviates on $[0,1]$, let

$$z_k = \begin{cases} a_1, & \text{when } 0 \leqslant x_k < p_1 \\ a_2, & \text{when } p_i \leqslant x_k < p_1 + p_2 \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots & k=1,2,\ldots \\ a_i, & \text{when } p_1+\ldots+p_{i-1} \leqslant x_k < p_1+\ldots+p_i \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots \end{cases}$$

with z_1, z_2, z_3,... as random samples of Z. We then have,

$$P\{Z_k = a_i\} = P\{p_1 + \ldots p_{i-1} \leqslant x_k < p_1 + \ldots + p_i\}$$

Since we assume that x uniformly distributes on [0,1], the right-hand side becomes,

$$(p_1 + \ldots + p_i) - (p_1 + \ldots + p_{i-1}) = p_i$$

therefore,

$$P\{Z_k = a_i\} = p_i$$

Now, we have a random variable Z_o with $\{p_i\}$ as the distribution, set the sample value as z_o, then

$$\{pz_o, j\}, \quad j=0,1,2,\ldots$$

as the probability distribution on j. We also can create

$$\{pz_o , i\}, \quad i=0,1,2,\ldots$$

as the probability distribution on i. Finally, we consider the $P=\{p_{ij}\}$ with

$$\begin{bmatrix} \theta<P_{11}<\theta & \theta<P_{12}<\theta & \cdots\cdots & \theta<P_{1n}<\theta \\ \theta<P_{21}<\theta & \theta<P_{22}<\theta & \cdots\cdots & \theta<P_{2n}<\theta \\ \vdots & \cdots\cdots\cdots & \cdots\cdots\cdots & \\ \theta<P_{m1}<\theta & & & \theta<P_{mn}<\theta \end{bmatrix}$$

in which, $P=P_o + \theta P$, θ is a fuzzy interval, $0\leqslant\theta\leqslant 1$.

This is the reality of a homogeneous, bistochastic Markov chain, with $\theta<<\{p_i\}>>\theta$ as initial distribution, $\theta<<\{P_{ij}\}<\theta$ as transition matrix.

In Markov based sets there is also reason to believe that the membership function relates to the physical properties of the set, as indicated by Rempfer, e.g., a communication system in which the signals received are noise contaminated. In the presence of a transmitted signal, the energy of the received signals will be the sum of the energies of the transmitted signals and the noise. The received signal is between 0 and 1. A fuzzy membership function may be explained in terms of the received signals when a transmitted signal exists. The defining feature of the elements of this set is their energy. The problem can be considered again as (see 3.3.2.),

$$y = cx + w$$

where c is constant, x and y are random numbers, x is considered as signal, and w is noise. The mean and variance of x and w can be calculated in terms of linear estimation theory, which in turn provides information for constructing membership functions just as Markov analysis does.

4.3.2. An Algorithm

Consider the following linear programming problem again:

$$\begin{aligned} \text{Maximize} \quad & CX \\ \text{s.t.} \quad & AX \leqslant B \\ & X \geqslant 0 \end{aligned} \qquad (4.1)$$

where A, B, and C have appropriate dimensions. This model can be fuzzified to a greater extent if instead of making A, B, and C exact numbers, fuzziness is introduced. This expression is analogous to Bellman and Zadeh's expression " x is in the neighbourhood of x_o " [63, p.B141]. In reality, A, B, and C can be fuzzified, i.e., coefficients of the decision problem are considered to have fuzziness. The fuzziness of A, B, and C affect the solution of any linear programming problem.

ζ (A) in the equation of an ellipsoid is exposed here as an example of fuzziness. From calculus [64], the equation of an ellipsoid with center at the origin can be represented as

$$1/2\, X^T AX = C \tag{4.3}$$

A is an n x n matrix, and c > 0.

At the point X of this ellipsoid, normal direction is,

$$1/2\nabla (X^T AX) = AX$$

If the normal direction is parallel to X,

$$AX = \lambda X \tag{4.4}$$

this direction is the direction of major axis, and $\|X\|$ is the length of semi axis. Then, substitute $AX_i = \lambda_i X_i$ into (4.3),

$$X_i^T AX_i = \lambda_i X_i^T X_i = 2c$$

then,

$$\left\| X_i \right\|^2 = 2c/\lambda_i \quad i = 1,2,\ldots,n \tag{4.5}$$

Assuming that

$$0< \lambda_1 \leqslant \lambda_2 \leqslant \ldots \leqslant \lambda_n$$

the longest and shortest semiaxes are,

$$\sqrt{\frac{2c}{\lambda_1}} \quad \text{and} \quad \sqrt{\frac{2c}{\lambda_n}}$$

(A) has the fuzzy range,

$$\frac{\lambda_n}{\lambda_1} = \zeta(A)$$

If $\zeta(A) = 1$, $\lambda_1 = \lambda_n$, and (4.3) becomes the representation of a sphere.

$CX \leqslant Z$ can be fuzzified or violated up to a higher limit, $C' = C + \delta C$,

$$CX + Y = C'X$$

where $Y = C'X - CX$, Y satisfies following condition,

$$0 \leqslant Y \leqslant C',$$

through Y we define the fuzzy membership grades.

Many non-fuzzy approaches and methods have been proposed in recent years to solve multiple objective linear programming [65, 66, 67, 68]. These methods can be grouped into two major headings: non-interactive and interactive methods. In the non-interactive method, a global preference function of the objectives is identified and optimized. In the interactive method, a local preference function is identified by interacting with the decisionmaker, and the solution process proceeds gradually toward the global solution. Most fuzzy multiobjective programming approaches are based on use of the intersection of fuzzy sets representing objectives and constraints, and on the subsequent maximization of the resultant membership function [69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82].

Here we present an approach based on interactive, iterative fuzzy evalution, which can be used to determine an imprecise solution to a multiobjective problem, especially in economic systems analysis.

The general multiobjective optimization problem with n decision variables, m constraints and p objectives is as follows:

$$\begin{aligned} \text{Optimize } C(x_1, x_2, \ldots, x_n) = [&C_1(x_1, x_2, \ldots, x_n), \\ &C_2(x_1, x_2, \ldots, x_n), \ldots, \\ &C_p(x_1, x_2, \ldots, x_n)] \end{aligned} \tag{4.6}$$

$$\begin{aligned} \text{s.t} \quad & g_i(x_1, x_2, \ldots, x_n) \leqslant 0 \qquad i=1,2,\ldots, m \\ & x_j \geqslant 0 \qquad j=1,2,\ldots, n \end{aligned}$$

The general purpose is to find optimal solution of the following problem:

$$\begin{aligned} \text{Optimize} \quad & u\, v(c(x)) \\ \text{s.t.} \quad & x \in X \\ & u \in [0,1] \end{aligned} \tag{4.7}$$

In the iterative process, v(c(x)) is known fuzzily from the beginning to the moment immediately before the decision is made. The possibility exists, furthermore, that new order may form right after the phase transition. In order to adapt to the decisionmaking in the real world, an interactive, iterative procedure is developed to be practical for decisionmaking. The method has the following features, based on those described in 2.3.:

1. It does not strive for predetermined objectives, but adapts to the dynamics of the decisionmaking process.

2. The interactive procedure helps include relevant factors for consideration, such as critical point, phase transition, and other factors. During the process of analysis, the decisionmaker can provide information which is crucial to the acceptability of the analysis.

3. Iteration: The iterative concept, which has roots in cybernetics and control theory, is quite useful in economic systems analysis. It examines economic systems analysis as a dynamic rather than a static process, with systematic iteration as an important characteristic. In a deterministic system, with a fixed, known coefficient and no stochastic element to the laws of motion, deterministic optimization can be used; but as soon as a stochastic element is introduced into the laws of motion, as it must be in economic systems analysis, then a different rule is needed. Information from the performance in earlier periods must be fed back into the system in order that the quasi-optimal path can be followed. An important task is to determine the decisionmaker's ultimate objective. The ultimate objective may be fuzzy, but many immediate objectives that lead toward it are fuzzier and include trial

and error. The iterative re-aiming algorithm [83] demostrates this idea vividly.

4. Learning: The concept of learning can be combined with a fuzzy algorithm. If actual outcomes violate the expectations of the decisionmaker, then presumably the decisionmaker will learn from the discrepancies and modify expectations. In attempting to develop theoretical models that explicitly incorporate the idea that decisionmakers respond differently through time as they gradually learn about the system, one is increasingly forced to emphasize learning, an essentially fuzzy process with parameters for variables subject to change as a result of learning [84, 85].

The basic assumptions are as follows:

1. Let $CX = \{Ci.x,\ i=1,2,\ldots,p,\ x \in X\}$. Assuming that decisionmaker's preference over solutions satisfies the following necessary and sufficient conditions:

(1). $v(c(x^1)) \geq v(c(x^2))$, $c(x^1)$ is preferred to $c(x^2)$;

(2). $v(c(x^1)) = v(c(x^2))$, $c(x^1)$ and $c(x^2)$ are equally desired.

2. $v(c(x))$ is concave, differentiable with continuous first partial derivatives in X.

3. X is convex, i.e., all points on a straight line segment joining any two points of the set belong to the set.

4. The overall value function is assumed to be

fuzzily known, a fuzzy linear function with the possibility of modification.

5. The objective function coefficients are linearly independent.

6. The algorithm requires the decisionmaker to adjust the aspiration level linguistically.

7. Solution is not an extreme point of the constraint set [66].

The algorithm is as follows:

1. Starting from suboptimization, determine x^i, $i=1,2,...,n$, n initial feasible solutions are created.

2. Determine the optimal solution of the multiobjective system as a whole.

3. Conduct fuzzy systematic evaluation of both subsystem and system.

4. Starting a subsystem-system search. A pattern of improving solutions is established for either a system solution vs. subsystems solution, or a subsystems solution vs. system solution.

5. Let x^* be the optimal solution to the last step. If it is a basic solution preferred by the decisionmaker, go to step 6. Otherwise, determine the decisionmaker's preferred solution in the direction of trade-offs among the objectives offered by nonbasic variables at x^* if they are preferred. If no non-basic variable at x^* offers desirable trade-offs among the objectives, go to step 6. If the non-

basic variable at x^x does not generate a feasible solution, discard it. Otherwise determine the decisionmaker's preferred solution in the direction of the trade-offs among the objectives offered by that variable, if they are desirable, go to step 6. If the trade-offs are undesirable repeat the forgoing process for some other non-basic variables. If no non-basic variable at x^x offers desirable trade-offs among the objectives go to next step. At this step, adjacent extreme points are examined.

6. Determine an efficient solution under fuzzified conditions. This step may involve the solution of step 1 to reach the decisionmaker's aspiration and then go to step 7.

7. The decisionmaker specifies objectives to be improved and worsened in the current solution, in accordance with fuzzy analysis. A feasible direction for the current solution that is likely to offer objective value changes is then determined. If the feasible direction determined offers desirable trade-offs among the objectives, determine the decisionmaker's preferred solution along them and proceed to step 8. Otherwise repeat the foregoing for other combinations of objectives. If no combinations lead to a solution preferable to the current one, terminate at the current solution if it is thought to be satisficing. Otherwise, perform a quasi-optimality check on it.

8. Determine the decisionmaker's preferred solution, in the direction of the established pattern of improving

solutions until satisficing solution is found. If the pattern of improving solutions changes, go back to step 7.

9. Determine, if an efficient solution that dominates the current one exist. If the determined solution is the same as or similar to the current one but is not satisficing, go back to step 7, and then go to step 8 until a momentary satisficing solution is obtained.

Detailed Description of Steps

Step 1

Set f as a real-valued function whose domain is a set U. f(u) is assumed to be bounded from below by m and from above by M. Then $0 \leqslant u_{\tilde{A}}(u) \leqslant 1$, A is a fuzzy set on U.

$$u\tilde{A}(u) = \frac{f(u)-m}{M-m}$$

Set $A_i \in F(U)$ $(i=1,2,...,n)$ as fuzzy objectives, $B_j \in F(U)$ $(j=1,2,...,m)$ as fuzzy constraints. Let

$$\tilde{D} = \tilde{A} \wedge \tilde{B}$$

the membership function is,

$$u\tilde{D}(u) = u\tilde{A}(u) \wedge u\tilde{B}(u)$$

finding the maximum on $B \varepsilon P(U)$ is equivalent to find u*, and make $u\tilde{D}(u^*) = \sup_{u \varepsilon U} u\tilde{D}(u)$.

Definition 4.1: $u^* \varepsilon U$ is called the element for maximizing f on $B \varepsilon F(U)$, if

$$u\tilde{D}(u^*) = \max_{u \varepsilon U} u\tilde{D}(u)$$

Now suppose both C and B in linear programming problems can be fuzzified, i.e., both objectives and constraints have inequal importance, and membership functions can be weighted by A_i and B_j-dependent coefficients a and b such that, the ith individually optimal solution, denoted x^i, is obtained as the optimal solution to the following problem,

$$uD(u) = a\,A_i(u) + b\,B_j(u) \qquad (4.8)$$

$$a + b = 1 \qquad (4.9)$$

$$a,\ b \geqslant 0$$

membership functions can be weighted for fulfilling a third possibility or slack behavior [1, 86] through fuzzy evaluation. The concept of general optimization in a fuzzy environment was originally proposed by Bellman and Zadeh [63].

The importance of linguistic input to the algorithm has been indicated by Mushkat [87]. The idea for using linguistic input expressed in this study is shared by Zeleny [88, p.169]:

> The task of a multiattribute weighting is complicated by a fuzzy logic employed by the decision maker when facing a not fully comprehensible problem. .... The newly developing theory of fuzzy set is intended to formalize such language.

Fuzzy linguistic input and linguistic hedge have also been introduced in evaluating membership functions.

The solutions in this step are the efficient solutions at which the ith objective takes a fuzzy optimal value over

X. It is advantageous if a and b can be chosen as close to the decisionmaker's preference, although it is subject to every change in decision systems. One fuzzy suboptimization solution to the problem is used as the first current solution. The ambiguity at issue here derives from fuzziness associated with the lack of a sharp transition from membership to nonmembership. According to Rempfer [17], this ambiguity stems from the randomness of a bistochastical process. The object can be the formulation of a fuzzy program to obtain a reasonable solution, given the ambiguity of the parameters. The fuzzy numbers can be regarded as a model of decisions in which human estimation, along with time, is significant.

Step 2

The optimization in a multiobjective system with n objectives and m constraints, and equal importance to objectives and constraints, is obtained as the solution to the following problem,

$$u\underset{\sim}{D}u = u\underset{\sim}{A}_i(u) \wedge u\underset{\sim}{B}_j(u) \qquad (4.10)$$

The equivalent is to find $u^* \varepsilon U$, and let

$$\underset{\sim}{D}(u^*) = \sup_{u \varepsilon U} u\underset{\sim}{D}(u)$$

Step 3

1. Set $X = \{x_1, x_2, \ldots, x_n\}$ as a set of objects;
2. Set $Y = \{y_1, y_2, \ldots, y_m\}$ as a set of criteria;
3. Set fuzzy relation from X to Y,

$$f: X \to F(Y)$$

$$x_i \to r_{i1}/y_1 + r_{i2}/y_2 + \ldots + r_{im}/y_m$$

$$0 \leqslant r_{ij} \leqslant 1, \; i=1,2,\ldots,n; \; j=1,2,\ldots,m$$

From f, the fuzzy relation R_f is introduced in terms of the fuzzy matrix,

$$R = \begin{bmatrix} r_{11} & r_{12} & \ldots & r_{1m} \\ r_{21} & r_{22} & \ldots & r_{2m} \\ & \ldots\ldots\ldots & & \\ r_{n1} & r_{n2} & \ldots & r_{nm} \end{bmatrix}$$

The vector of x_i $R|x_i = (r_{i1}, r_{i2}, \ldots, r_{im}) \varepsilon [0,1]^m$;

4. Set the evaluation function $f:[0,1]^m \to R$, as

$$E = f(z_1, z_2, \ldots, z_m)$$

5. Calculate an evaluation index: $E(x_i) = f(r_{i1}, r_{i2}, \ldots, r_{im})$, $i \leqslant m$.

The triple (X,Y,R) is called an evaluation space.

For f, the following conditions are satisfied:

1. regularity: $f(0,0,\ldots,0)=0$;

2. monotonicity: when $z_i \leqslant z_i'$, $f(z_1, z_2, \ldots, z_m) \leqslant f(z_1', z_2', \ldots, z_m')$, $i \leqslant m$;

3. continuity: $\lim_{\substack{z_i \to z_{io}}} f(z_1, z_2, \ldots, z_m) = f(z_{1o}, \ldots, z_{mo})$.

In the proof, other conditions will be specified.

Lemma 4.1: Set monotonic function ζ: $[0,1] \to R$,

$$\zeta(x+y) = \zeta(x) + \zeta(y), \ (\forall x, y, x+y \in [0,1]),$$

$$\zeta(x) = ax, \ a = \zeta(1) \geqslant 0.$$

Proof: $\zeta(0+0) = \zeta(0)+\zeta(0), \zeta(0)=0$, for natural number n, $\frac{1}{n} \in [0,1]$,

$$\zeta(1) = \zeta(\frac{1}{n} * n) = n\,\zeta(\frac{1}{n})$$

let $\zeta(1) = a$, $\zeta(\frac{1}{n}) = a * \frac{1}{n}$, for $\frac{m}{n} \in [0,1]$, n, m are natural numbers, $n \geqslant m$,

$$\zeta(\frac{m}{n}) = \zeta(\frac{1}{n} * m) = \zeta m(\frac{1}{n}) = a * \frac{m}{n}$$

therefore, if $r \in [0,1]$ is a rational, $\zeta(r) = a * r$.

Then set ξ as any real number between $[0,1]$, take a_n, b_n, let $a_i < \xi < b_i$. From monotonity, $a\,a_i < \zeta(\xi) < a\,b_i$, $i \to \infty$, $a\,\xi \leqslant \zeta(\xi) < a\xi$. Therefore, for $\forall\, x \in [0,1], \zeta(x) = ax, \zeta a = (1) \geqslant 0$.

Theorem 4.1: $f:[0,1]^m \to R$ satisfies regularity, monotonicity, and

$$f(z_1+z_1',\ldots,z_m+z_m')=f(z_1,\ldots,z_m)+g(z_1',\ldots,z_m')$$

$$g:[0,1]^m \to R.\quad f(z_1,z_2,\ldots,z_m)=a_1 z_1+\ldots+a_m z_m=\sum_{i=1}^{m} a_i z_i$$

a_i is nonnegative constant.

Proof: according to regularity,

$$f(z_1',z_2',z_m')=f(0,0,\ldots,0)+g(z_1',z_2',\ldots,z_m')$$
$$=g(z_1',z_2',\ldots,z_m')$$

then, $f(z_1+z_1',\ldots,z_m+z_m')=f(z_1,\ldots,z_m)+f(z_1',\ldots,z_m')$

let $f_1(z_1)=f(z_1,0,\ldots,0)$, $f_2(z_2)=f(0,z_2,0,\ldots,0)$

$f_i(z_i)=f(0,\ldots,z_i,0,\ldots,0)$, $i\leqslant m$, using the result from lemma 1, $f_i(z_i)=a_i z_i$, $a_i\geqslant 0$, $i\leqslant m$, then

$$f(z_1,\ldots,z_m)=f(z_1,0,\ldots,0)+f(0,z_2,0,\ldots,0)+\ldots+f(0,\ldots,0,z_m)$$
$$=\sum_{i=1}^{m} f_i(z_i)$$

since $f_i(z_i)=a_i z_i$, $\sum_{i=1}^{m} f_i(z_i)=\sum_{i=1}^{m} a_i z_i$. This linear homogeneous function satisfies regularity, monotonicity, and another above-mentioned conditions.

Lemma 4.2: Set ζ: $[0,1]\to[0,1]$, satisfies regularity, monotonocity, and continuity, also satisfies

$$\zeta(\zeta(x))=\zeta(x),\quad \forall x\in[0,1],$$

$$\zeta(x)=a\wedge x,\quad a=\zeta(1),\ \wedge \text{is min operator}.$$

Proof: ζ is monotonic and continuous ε [0,a], take $x\,\varepsilon$ [0,a], there exists

$y\,\varepsilon[0,1]$: $x=\zeta(y)\leqslant a$, then

$\zeta(x)=\zeta(\zeta(y))=\zeta(y)=a\wedge\zeta(y)=a\wedge x$.

If $a<x\leqslant 1$, $a=\zeta(\zeta(1))=\zeta(a)\leqslant\zeta(x)\leqslant\zeta(1)=a$, $\zeta(x)=a\wedge x=a$.

Theorem 4.2: Set $f:[0,1]^m\to[0,1]$ satisfies regularity, continuity, and

1. $f(z_1\vee z_1',\ldots,z_m\vee z_m')=f(z_1,z_2,\ldots,z_m)\vee g(z_1',z_2'\ldots,z_m')$

2. $f_i(f_i(z_i))=f_i(z_i)$, $f_i(z_i)=f(0,\ldots,0,z_i,0,\ldots,0)$, $i\leqslant m$

$g:[0,1]^m\to[0,1]$, $f(z_1,z_2,\ldots,z_m)=(a_1\wedge z_1)\vee(a_2\wedge z_2)\vee\ldots\vee(a_m\wedge z_m)$, $a_1,\ldots,a_m\,\varepsilon[0,1]$.

Proof: according to regularity,

$$f(z_1',\ldots,z_m')=f(0,\ldots,0)\vee g(z_1',\ldots,z_m')=g(z_1',\ldots,z_m')$$

$$f(z_1\vee z_1',\ldots,z_m\vee z_m')=f(z_1,\ldots,z_m)\vee f(z_1',\ldots,z_m')$$

f is monotonic,

$$f(z_1\vee 0,\ldots,z_m\vee 0)=f(z_1,\ldots,0)\vee\ldots\vee f(0,\ldots,0,z_m)$$
$$=\bigvee_{i=1}^{m} f_i(z_i)$$

since f satisfies regularity, monotonicity, and continuity, therefore,

$$f_i(z_i)=a_i \wedge z_i$$

$$f(z_1,\ldots,z_m)=(a_1 \wedge z_1) \vee \ldots \vee (a_m \wedge z_m)$$

$a_i=f_i(1) \in [0,1]$, $i \leqslant m$.

For alternative proofs, see [89]. For the Lemma 4.3 and Theorem 4.3, the results described here are proved by Wu [89].

Lemma 4.3: Set $\zeta:[0,1] \to [0,1]$

$$\zeta(xy)=\zeta(x)\,\zeta(y) \qquad \forall\ x,y \in [0,1]$$

$\zeta(0)=0$, $\zeta(1)=1$, $\zeta(x)=x^a$, a is positive real number.

Theorem 4.3: Set $f:[0,1]^m \to [0,1]$, it satisfies regularity, continuity, and the following:

1. $f(z_1 \wedge z_1', \ldots, z_m \wedge z_m')$

   $= f(z_1,\ldots,z_m) \wedge g(z_1',\ldots,z_m')$

2. let $\zeta_i(z_i)=f(1,\ldots,1,z_i,\ldots,1)$

   $\zeta_i(z_i z_i')=\zeta_i(z_i)\,\zeta_i(z_i') \qquad i=1,\ldots,m$

   $\zeta_i(0)=0$

3. $f(1,1,\ldots,1)=1$

Proof: let $z_1=z_2=\ldots=z_m=1$

$$f(z_1',\ldots,z_m')=f(1,\ldots,1)\wedge g(z_1',\ldots,z_m')=g(z_2',\ldots,z_m')$$

$$f(z_1\wedge z_1',\ldots,z_m\wedge z_m')=f(z_1,\ldots,z_m)\wedge f(z_1',\ldots,z_m')$$

$$f(z_1,\ldots,z_m)=f(z_1,1,\ldots,1)\wedge\ldots\wedge f(1,\ldots,1,z_m)$$

$$=\zeta_1(z_1)\wedge\ldots\wedge\zeta_m(z_m)$$

$$\zeta_i(z_i)=z_i^{a_i}$$

As Negoita [90, p.125] notes:

> The notions of subjective evaluations and of fuzzy sets are not one and the same but rather have the relationship of goal and tool: having precisely manipulatable subjective evaluations is the goal, and fuzzy set theory is a tool to achieve the goal.

Step 4

Systematic search in this step aims to determine a pattern of improving solutions, preferred by the decisionmaker and carried out over objective space.

Since $x_i \varepsilon X$, the objective space direction defined by $c(x_i)$ and $c(x_k)$ is denoted by $(c(x_i), c(x_k))$. If $c(x_i)$ is the current solution, the decisionmaker is asked to indicate a preferred, fuzzified, feasible solution $c(x_{i+1})$ in the direction of $(c(x_i), c(x_k))$. Then the decisionmaker is asked to indicate in turn $c(x_{i+2})$ in the direction of

$(c(x^i),c(x^k))$. If $c(x^i) \neq c(x^k)$, the pattern of improving solution for whole-subsystems is established. If $c(x^i)=c(x^k)$, no pattern of improving solutions has been determined.

Theorem 4.4: If $c(x^i)$ is an efficient solution, and $c(x^j)$ is an efficient solution, there will be a set of efficient solutions inbetween.

Proof: Set k=0,1,...,n as parametric space, then both $c(x^i)$ and $c(x^j)$ have their $k1(x^i)$ and $k2(x^j)$ respectively. Because of the convexity of k=n, we know that k1 and k2 is contained in the union of all polyhedra which are associated with bounded solutions. Because of a finite covering of k=n, we can select a finite sequence of distinct polyhedra $\{x^{i+1},...,x^{i+k}\}$, such that $k(x^{i+k})=k(x^j)$ in accordance with a and b.

The fuzzified feasible solution in the direction of improving is as follows:

$$c(x^x)=c(x^i)+u(c(x^k)-c(x^i))$$

Optimize u

$$\text{s.t. } c(x^x)=c(x^i)+u(c(x^k)-c(x^i))$$

$$x \in X$$

$$u \in [0,1]$$

(x^x) would then be the decisionmaker's preferred solution. The objective function varies with u, which is a function of decisionmaker's fuzzy judgment. In this step, the diversification is toward centralization.

Step 5

Let x^x be the current optimal solution. When x^x is not a basic solution preferred by the decisionmaker, the decisionmaker's preferred solution in the direction of desirable trade-offs among the objectives offered by some non-basic variables at x^x is determined as follows:

Theorem 4.5 : Given a current basic feasible solution, and assuming $\theta_j \geqslant 0$ for $j \in \bar{J}$, then, if $z_j \leqslant 0$, then the basic is inferior [88, p.66].

Proof: Introducing the jth column into the basis, we ascertain a new adjacent extreme point, for which $\hat{z}_0 \geqslant z_0$.

Theorem 4.6 : If $z_j \geqslant 0$, then introducing the jth column into the basis will lead to an inferior solution [88, p.66].

Proof: Introducing the jth column, we find an adjacent extreme point for which $\hat{z}_0 \leqslant z_0$, since $-\theta_j z_j \leqslant 0$.

Theorem 4.7 : Given a current basic, feasible solution, if there are two different, nonbasic columns j and k, such that

$$\theta_j z_j \leqslant \theta_k z_k \quad , \quad j \neq k, \ j,k \in \bar{J},$$

then the solution resulting from introducing the kth column is dominated by the solution resulting from introducing the jth column [88, p.67].

Proof: Introducing the kth column, we get $\hat{z}_0$; and introducing the jth column, we get $\hat{\hat{z}}_0$. Then $\hat{z}_0 = z_0 - \theta_k z_k$ and $\hat{\hat{z}}_0 = z_0 - \theta_j z_j$. Since $-\theta_k z_k \leqslant -\theta_j z_j$, then $\hat{z}_0 \geqslant \hat{\hat{z}}_0$.

The set of fuzzified feasible solutions in the objective space direction $c(a^j)$ at $c(x^x)$ is as follows:

$$\begin{aligned}
&\text{Optimize } u \\
&\text{s.t. } c(x)=c(x^x)+u(c(a^j)) \\
&\qquad u \in [0,1] \\
&\qquad x \in X
\end{aligned}$$

The jth non-basic variables can be either x_i or s_i. The non-basic s_i at x^x changes fuzzily in value, solutions generated will lie on the same face of x^x if no basic variables change values [91].

Step 6

This step explores the possibility that if the current solution is efficient, a fuzzified preferred solution can be determined, too.

This step is a special case for step 4.

Theorem 4.8: When $k(x^i)$ equals $k(x^j)$, the solution reaches its boundary.

Proof: The proof follows directly from the last theorem. Because of a finite covering of k=n, a line segment $[k(x_i),k(x_j)]$ is contained in the union of all polyhedra associated with the boundary.

Let $c(x^x)$ be the current solution. Solve the following problem:

$$\begin{aligned} &\text{Maximize} && u(x_i) \\ &\text{s.t.} && c_i x - x_i = c_i x \quad i=1,2,\ldots,n \\ &&& x \in X \\ &&& u \in [0,1] \end{aligned}$$

If the solution of the problem equals zero, u=1. If the solution $\geqslant 0$, $0 \leqslant u \leqslant 1$.

Step 7

Systems research, in contrast with applied mathematics, is problem- rather than tool-oriented [59]. In ill-structured systems, inexact information and value-based judgment are common. In consequence, many sophisticated mathematical analyses, such as the gradient method, often encounter difficulties in measurement, inference, and application [92]. Judgment prevails in place of precise analysis, and approximation instead of exact solutions. In order to discover how effective the various fuzzy alternatives are in achieving the objectives, it is necessary to determine a way to measure their effectiveness, again involving fuzzy value judgment.

Broadly, fuzzy integral is appropriate for evaluation [46, p.127]. The systematic evaluation of the object can be summarized as follows: set $U=\{u_1, u_2, \ldots, u_n\}$ be a set of elements or attributes. Let $h: \to U\ [0,1]$,

$$\int h(u) \circ g$$

Set $A' = U_i = \{u_1, u_2, \ldots u_i\} \varepsilon U$, and $h(u_i)$ as the function on U:

$$h(u_1) \geqslant h(u_2) \geqslant \ldots \geqslant h(u_{i\,n}),$$

then, $\int_A h(u) \circ g \cdot = \int_{U_i} h(u_i) \cdot g \cdot = \overset{V}{_{i=1}} [h(u_i) \wedge g(u_i)],\ u_i \varepsilon\ U_i$.

Set distribution function as,

$$H(u_1) \leqslant H(u_2) \leqslant \ldots \leqslant H(u_n) = 1,$$

let $g_\lambda(U_i) = H(u_i)$,

define the following,

$$g_1 = H(u_1)$$

$$g_i = \frac{H(u_i) - H(u_{i-1})}{1 + _\lambda H(u_{i-1})} \qquad (2 \leqslant i \leqslant n)$$

for any $U \sqsubseteq U$,

$$g_\lambda(U') = \frac{1}{\lambda} [\prod_{ui\,\varepsilon U'} (1 + _\lambda g_i) - 1]$$

for $U=\{u_1, u_2, \ldots, u_n\}$,

$$\{u_1\} = U_1 \subseteq U_2 \subseteq \ldots \subseteq U_n = U$$

then

$$H(u_1) \leqslant H(u_2) \leqslant \ldots \leqslant H(u_n) = 1$$

$$g_\lambda(U_1) \leqslant g_\lambda(U_2) \leqslant \ldots \leqslant g_\lambda(U_n) = 1$$

$$\bigvee_{i=1}^{n} [\, h_{u \varepsilon U_i}(u_i) \wedge g(U_i)] \quad \bigvee_{i=1}^{n} [h(u_i) \wedge H(u_i)]$$

$$(i \leqslant j,\ h(u_i) \leqslant h(u_j)),$$

i.e., $\int_U h(u_i)\, g = \bigvee_{i=1}^{n} [h(u_i) \wedge H(u_i)]$

The decisionmaker is expected to assign relative weights to the desired changes of individual objectives. The result is an efficient solution, and that may involve Tremolieres's crisp solution [93]. The new objective function can be formulated accordingly to improve the likelihood of determining a desirable feasible direction at x^x. The problem also can be reformulated fuzzily and referred back to first step. When the decisionmaker is no longer wishes to re-specify fuzzy formulations, go to step 8.

Step 8

Again, the fuzzified feasible improving solution in the desirable direction is as follows:

$$c(x^{x+1})=c(x^{x})+u(c(x^{x+1})-c(x^{x}))$$

$$\text{Optimize } u$$
$$\text{s.t. } c(x^{x+1})=c(x^{x})+u(c(x^{x+1})-c(x^{x}))$$
$$x \in X$$
$$u \in [0,1]$$

Step 9

If the decisionmaker no longer wishes to re-specify fuzzy formulation, or if there exists an efficient satisficing solution dominating the current solution, the solving procedure is terminated. The question of what is satisfactory is largely answered by judgment. The preferred alternative is the one that, in the decisionmaker's value judgment, yields the greatest positive consequence. At this step, a relative equilibrium has been reached, a state of the system satisficing partial basic consistency conditions that makes it self-perpetuating once attained.

As many ill-structured systems methods in applied systems analysis, both the conventional economic systems analysis or current modified economic systems analysis have no stopping rule to tell the decisionmaker where the solution is. There may be an immediate solution, but not an ultimate one. The decision consists of flows, as described in Chapter 3, that only can be described in terms of the instantaneous state of the system. There is no solution but resolution, which relies on judgment. Due to the multidimensional perspectives, even the decisionmaker may not really know where the objectives are.

The reason for designing the first and second steps of the algorithm is that whenever multiple objectives are present in a project, there is probably no single course of action that will optimize all objectives simultaneously. In the environment-related projects, more decisionmakers have now been convinced that the pursuit of the perfectly clean, safe environment will involve either unacceptably high costs or intrusive social impacts.

This contradiction may lead to suboptimization, a solution that optimizes subsystem efficiency with inadequate or no regard for system effectiveness. At the first step, the decisionmaker is imperfectly aware of the system, and incompletely describes the economic or other system. The reason for entering step two is the question of what other system will be operated in parallel. The subsystems are parts of the system. Only when the system has been completely defined will there be a real analysis. Then, a reasonable response would be for the decisionmaker to change the model or its parameters to accommodate the observations made. After performing steps one and two, the task is to find an equilibrium between subsystem and system. In other words, the decisionmaker adapts to the variations in the picture of the system perceived, thus arriving at the equilibrium point.

The system sets ultimate objectives, and the associated subsystems define the multiple strategems required to achieve those objectives. A systems decision selects the overall objective that best utilizes the available resources. The relationship between system and subsystems offers constructive insight in Step 3. The effectiveness of each subsystem is estimated from its effect on system objectives. It could happen that a system with lower effectiveness possessed the subsystem with the highest efficiency. Suppose that subsystem X were close to the most efficient subsystem of system I. If it were highest in efficiency, it might be the leading alternative for selection, in its systematic evaluation. X might have high sensitivity, such that it was vulnerable to changes in the system. If it were sensitive on the efficiency scale, a change in either the system or even the wider system could switch the position of the top subsystems, or even the system itself. An insensitive situation might occur, in which all the subsystems for a given system had a higher efficiency than the best subsystem of any other system. The consequence of high sensitivity would be to force a comprehensive estimation to assure the appropriateness of X. A fuzzy analysis could be conducted on projects to explore systems effectiveness.

4.3.3. An Illustrative Example

A simple numerical example illustrates the approach. Suppose a hydropower administration designs two kinds of dam on given conditions. Dam 1 yields a benefit of $2 million annually, and dam 2 of $1 million. Dam 2, however, improves existing natural scenery, yielding additional yearly recreational revenues of $2 million dollars, dam 1 has annual negative environmental impacts of $1 million. Two goals are established: 1. Benefit maximization, and 2. Maximum improvement of the natural environment. The problem can be modeled as follows:

$$\text{Max} \quad c_1 x = 2x_1 + x_2 \quad \text{economic benefits}$$

$$c_2 x = -x_1 + 2x_2 \quad \text{effect on natural environment}$$

$$\text{s.t.} \quad -x_1 + 3x_2 \leqslant 21$$

$$x_1 + 3x_2 \leqslant 27$$

$$x_1 \geqslant 0$$

$$x_2 \geqslant 0$$

Single Objective Optimization

Economic benefits-maximization solutions:

$$x_1 = 27$$

$$Z = 54$$

Natural environment-improvement maximization solution:

$$x_2 = 7$$

$$Z = 14$$

Fuzzy Multiobjective Programming

Step I

The union and intersection can be defined as follows:

$u_A \vee u_B = u_{A \vee B}(x) = \max(u_A(x), u_B(x)), \quad x \in X$

$u_A \wedge u_B = u_{A \wedge B}(x) = \min(u_A(x), u_B(x)), \quad x \in X$

and the complement $u_{\bar{A}}$ of u_A has a membership function $1-u_A$.

For normalization, language hedges are applied. Suppose Objective I's membership function is .9 in economic measure, and .4 in social impacts,

$.9 \wedge .4 = .4$

and objective II's membership function is .6 in social impact, and .3 in economic measure, thus

$.6 \wedge .3 = .3$

the decisionmaker may normalize the two measures into u_A relatively=$(u_A)^{.75}$, such as .5029734 and .40536 respectively. The relevant weight for objective I is .57 or .55. The relevant weight for objective II is .43 or .44.

Max $c_1 = .50(2x_1 + x_2)$

$c_2 = .50(-x_1 + 2x_2)$

solution:

$x_1 = 3$

$x_2 = 8$

$Z=27$

Step II

$\text{Max } c_1 = .57(2x_1 + x_2)$

$c_2 = .43(-x_1 + 2x_2)$

solution:

$x_1 = 3$

$x_2 = 8$

$Z = 23.75$

Step III

$\text{Set } X = \{x_1, x_2\}$

$Y = \{y_1, y_2, y_3, y_4\}$

y_1 :economic measure(IRR, ERR, or B:C ratio, etc.,)

y_2 :systems-subsystems trade-off

y_3 :systems-subsystems effectiveness

y_4 :social impacts

$$R \quad \begin{array}{c} \\ x_1 \\ x_2 \end{array} \begin{array}{cccc} y_1 & y_2 & y_3 & y_4 \\ \hline .9 & .7 & .6 & .4 \\ .5 & .4 & .8 & .6 \end{array}$$

E_1 =average

E_2 =max

E_3 =min

E_4 =marginal analysis

$$R_1 \quad \begin{array}{c|cccc|} & E_1 & E_2 & E_3 & E_4 \\ x_1 & .65 & .9 & .4 & .6 \\ x_2 & .56 & .8 & .4 & .5 \end{array}$$

Step IV

Max $c_1 = .53(2x_1 + x_2)$

$c_2 = .47(-x_1 + 2x_2)$

solution:

$x_1 = 3$

$x_2 = 8$

$Z = 25.49$

Step V

The current solution is the best compromise solution.

Step VI

Max x_3

s.t. $3x_1 + 8x_2 = 27$

$3x_1 + 8x_2 - x_3 = 25.49$

solution:

$x_3 = 1$

$Z = 1.057$

Step VII

Now we evaluate two kinds of dam again in terms of fuzzy integral. The weight has been changed, and the decisionmaker may therefore change the evaluation again.

set u_1 =economic efficiency

u_2 =systems effectiveness

u_3 =social impacts

u_4 =intergeneration consideration

u_5 =other considerations

for objective I

		u_1	u_2	u_3	u_4	u_5
Degree of Satisfaction	$h(u_i)$	1	.8	.5	.2	.1
Degree of Emphasis	$g_i(\lambda=0)$	.5	.2	.1	.1	.1
Distribution Function	$H(u_i)$	.5	.7	.8	.9	1
Degree of Emphasis	$g_i'(\lambda=0)$	.2	.1	.1	.2	.4
Distribution Function	$H'(u_i)$	.2	.3	.4	.6	1

With the systematic evaluation under the degree of satisfaction $h(u_i)$, the degree of emphasis g_i is as follows:

$u=(1\wedge.5)\vee(.8\wedge.7)\vee(.5\wedge.8)\vee(.2\wedge.9)\vee(.1\wedge1)=.7$

With the systematic evaluation under the degree of satisfaction $h(u_i)$, the degree of emphasis g_i' is as follows:

$u=(1\wedge.2)\vee(.8\wedge.3)\vee(.5\wedge.4)\vee(.2\wedge6)\vee(.1\wedge1)=.4$

for objective II

		u_1	u_2	u_3	u_4	u_5
Degree of Satisfaction	$h(u_i)$	.8	.9	.6	.3	.2
Degree of Emphasis	$g_i(\lambda=0)$	.5	.2	.1	.1	.1
Distribution Function	$H(u_i)$	.5	.7	.8	.9	1
Degree of Emphasis	$g_i'(\lambda=0)$	.2	.1	.1	.2	.4
Distribution Function	$H'(u_i)$	.2	.3	.4	.6	1

With the systematic evaluation of objective 2 under the degree of satisfaction $h(u_i)$, degree of emphasis g_i is as follows:

$u=(.8\wedge.5)\vee(.9\wedge.7)\vee(.6\wedge.8)\vee(.3\wedge.9)\vee(.2\wedge1)=.7$

With the systematic evaluation of objective 2 under the degree of satisfaction $h(u_i)$, degree of emphasis g_i' is as follows:

$u=(.8\wedge.2)\vee(.9\wedge.3)\vee(.6\wedge.4)\vee(.3\wedge.6)\vee(.2\wedge1)=.4$

Step VII

Max $c_1x=.50(2x_1+x_2)$

$c_2x=.50(-x_1+2x_2)$

solution:

$x_1=3$

$x_2=8$

$Z=27$

Step IX

End

Markov analysis has been applied for finding membership functions of multiobjectives in terms of a Monte Carlo method.

III. Empirical Data for Initial Distribution of Objective I

Importance	Probability	Cumulative Probability
0%	.00	.00
25%	.25	.25
50%	.55	.80
75%	.10	.90
100%	.10	1.00

IV. Simulation Results for Initial Distribution of Objective I

Sample	Random Number	Importance
1	60	50%
2	68	50%
3	8	0%
4	87	75%
5	53	50%
6	67	50%
7	48	50%
8	90	75%

$$E(X) = \sum x_i f(x_i)$$

$$= .5$$

V. Empirical Data for State Transition

of Objective I

State 1	Probability	Cumulative Probability
.2	.00	.00
.4	.15	.15
.6	.15	.30
.8	.60	.90
1.00	.10	1.00

VI. Simulation Results for State Transition

of Objective I

Sample	Random Number	State 1
1	12	.2
2	23	.6
3	75	.8
4	64	.8
5	46	.8
6	41	.8
7	78	.8
8	23	.6

E(X)=.675

VII. Empirical Data for State Transition

of Objective II

State 1	Probability	Cumulative Probability
.2	.00	.00
.4	.15	.15
.6	.15	.30
.8	.60	.90
1.00	.10	1.00

VIII. Simulation Results for State Transition

of Objective II

Sample	Random Number	State 1
1	53	.8
2	23	.6
3	33	.8
4	32	.8
5	61	.8
6	75	.8
7	57	.8
8	50	.8

$E(X)=.775$

The Markov transition process can be expressed as follows:

$$
\begin{array}{cc}
 & \begin{array}{cc} \mathrm{I} & \mathrm{II} \end{array} \\
(.5,\ .5) & \begin{array}{c} \mathrm{I} \\ \\ \mathrm{II} \end{array}
\begin{vmatrix} \theta<.675<\theta & \theta<.325<\theta \\ & \\ \theta<.325<\theta & \theta<.675<\theta \end{vmatrix}
\end{array}
$$

The following two examples provide some information about how the signal is transmitted with noise (for a further explanation see [17]). They demonstrate that state correspondence matches the concatenation of empirical data supporting probabilistic dynamics as a fundamental causality.

$$
\begin{array}{cc}
 & \begin{array}{cc} \mathrm{I} & \mathrm{II} \end{array} \\
(.5,\ .5) & \begin{array}{c} \mathrm{I} \\ \\ \mathrm{II} \end{array}
\begin{vmatrix} .698 & .3 \\ & \\ .302 & .68 \end{vmatrix}
\end{array}
$$

$$=(.5,\ .49)$$

$$(.5,\ .49)\ \begin{array}{c|cc|} & \text{I} & \text{II} \\ \text{I} & .695 & .302 \\ \text{II} & .3 & .689 \end{array}$$

$$=(.4945,\ .48861)$$

Generally speaking, we have a system in which ~ is denoted as stochastic vector,

$$(\sim,\sim)\ \begin{array}{c|cc|} & \text{I} & \text{II} \\ & \sim & \sim \\ & \sim & \sim \end{array}$$

and therefore, the states after infinite steps are always fuzzy.

CHAPTER 5

SUMMARY, CONCLUSION, AND SUGGESTIONS FOR SUBSEQUENT RESEARCH

A model is always an approximation,..., and hopefully an aid to insight.

H. Borko [94, p.39]

This final chapter looks backward and forward: back to summarize the previous chapters and to make the major conclusions; ahead to indicate the directions subsequent research might take.

5.1. Summary

The introductory chapter scrutinizes classical economic systems analysis, two schools of economic systems analysis, and the major characteristics of conventional methodology. The chapter also explains the motivation for conducting this study, emphasizing the growing importance of ill-structured systems methodology as the main element of economic systems analysis.

Chapter 2 proposes a synergetic philosophical paradigm to replace the Newtonian-Kantian inquiring system as the foundation of methodology. The chapter concludes with a methodological overview of economic systems analysis, pointing to a new approach for the 1980s and beyond.

Chapter 3 elucidates systems synthesis and systems analysis as the two most important steps in economic systems analysis, beginning with a description of the synergetic, autopoietic, and H-type characteristics of these two steps in terms of multidimensional motion. Synergetic, autopoietic, and H-type characteristics depict the process of multidimensional motion. The conclusion is that constant redefinition is essential, and relatively less effort is needed for an optimization effort.

Chapter 4 begins with the proposition that science equals truthfulness, randomness, and fuzziness, and then introduces Rempfer's Markov communication theory and fuzzy sets theory as tools for handling randomness and fuzziness in multiobjective analysis. The important result is a fuzzy multiobjective mathematical programming algorithm.

Chapter 5 summarizes, concludes, and points out suggestions for subsequent research.

5.2. Conclusion

Two decision models have been constructed: a synergetic interaction model for problem formulation and analysis, and a fuzzy multiobjective mathematical programming algorithm for multiobjective analysis. Fuzzy modeling offers a deeper understanding and clear explication of an event's complexities, and a means for incorporating subjective inputs and adaptation. Therefore, fuzzy modeling increases the validity of the systems approach for dealing with ill-structured systems. The method responds to the current trends in economic systems analysis, multiobjective mathematical programming, and systems theory [59, 66].

For economic systems analysis, we improve steps 1, 2, and 5 (see p.3) in terms of fuzzy reasoning, and develop a new fuzzy algorithm for multiobjective programming. For systems theory, general interaction and other relevant concepts have been developed.

Our initial experience with the algorithm has indicated that,

(1) the method, which is simple and permits easy interaction with the decisionmaker, can provide the required information without significant difficulty. The algorithm, characterized by a progressive articulation of preference, is not difficult for a decisionmaker to understand. Progressive articulation iteratively gives decisionmakers information on the consequences of their value judgments and allows them to modify their choices in an effort to improve the solution.

Generally speaking, the method is appropriate to the problem to which it is applied, to the decisionmakers who will use it, and to the organizational setting in which it will be implemented. The method allows an explicit consideration of external and internal perspectives.

Therefore, it is appropriate in regard to the types of alternatives it can consider, the value judgments it requests, and the forms of evaluations it yields. It represents an important methodological improvement over Marglin's approach;

(2) The method can provide the room for both systematic and chance observations, and it is closer to reality in comparison with the balance-sheet, goal achievement matrix, and rank-based expected value methods;

(3) Fuzzy evaluation offers an appropriate way to deal with a problem in which many factors must be evaluated simultaneously. The appropriate weighting base on numerous factors makes it possible to approximate reality more closely, as the Rempfer algorithm proves mathematically [83];

(4) The method is particularly suitable to situations in which a decisionmaker tends to provide linguistic measures in the solution process;

(5) The algorithm establishes a learning process. As Negoita [90, p.126] indicates:"In fuzzy evaluations 'the best' is viewed as a new evaluation in the structure of all evaluations, pulling back towards a synthesis." The idea of iteration in a fuzzy environment incorporated in this algorithm has been stated profoundly by Rempfer's algorithm [83] and Negoita's comments.

Basically, the task proposed at Chapter 1 has been completed.

5.3. Suggestions For Subsequent Research

This work has not spoken the last word on the application of fuzzy multiobjective programming to economic systems analysis; it is only the beginning.

The following areas would merit further study:

(1) Fuzzy methodology fills many of the gaps left by non-fuzzy methods. However, reduction is still available in the modeling process. Therefore, there is a long way to go toward realizing the proposed paradigm as a solid foundation of the methodology;

(2) A general, fuzzy description for bridging the language gap will be of great value to steps 3 and 4. The construction of relevant fuzzy functions must be emphasized;

(3) Investigators should consider the extent to which the method may be suitable to allow a multiobjective programming solution;

(4) Large-scale Markov analysis using computers should be emphasized;

(5) The effect of H-substance on systems design requires consideration.

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APPENDIX A: LIST OF SYMBOLS

$=$	equal to
$\leqslant$	less than
$\geqslant$	greater than
$\forall$	for all
ε	belongs to
$P(X)$	set of subsets of X
R	set of real numbers
$\|a\|$	absolute value of the number a
$\sum_i$	sum of numbers indexed by i
u_A	membership function of a fuzzy set A on a universe U
$\vee$	intersection of fuzzy sets
$\wedge$	union of fuzzy sets
$R \circ Q$	sup-min composition of the fuzzy relations R and Q
$\int$	Sugeno's integral