



Multiple Criteria Decision Methods and Applications

Selected Readings of the
First International Summer School
Acireale, Sicily, September 1983

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In Collaboration with Benedetto Matarazzo

With 56 Figures and 35 Tables

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Preface

Both the 'First International Summer School on Multiple Criteria Decision Making Methods, Applications and Software' and the present volume of readings could only be realised with assistance and support from many sides. We would like to express our gratitude to all those who have contributed to making a success of the first of a hopefully long series of summer schools in this field and to all those who have contributed to the present volume.

First of all we are grateful for the financial means supplied by a long list of sponsors, the most important of which are mentioned on the copyright page. Next, we are grateful to the members of the organising committee, Anna Ostanello and Giovanni Zambruno. Since this is the first of what will become a series of summer schools, the chairman of the organising committee, Benedetto Matarazzo, will start this volume with a brief account of the school held in Acireale. The programme committee consisted of Jean Fichet, Anna Ostanello, Bernard Roy, Jaap Spronk (chairman) and Stanley Zionts. Their valuable contribution is gratefully acknowledged, as is the contribution of all the lecturers at the school. Of course, a school is not only made by its teachers, but just as much by its students. The primary aim of a school is to teach and to stimulate the students. It is a tribute to the quality of the students to notice that their presence and attitude was in its turn very stimulating and instructive to the lecturers. During the school, many contacts have been made, contacts of a long-lasting character, both at the professional and at the personal levels.

The present volume of readings is for the most part, a selection of what was presented at the school. A number of the papers was presented in pretty much the same form as they appear here. Others have been adapted and reworked in order to let them fit into the framework of this volume. In addition, one contribution (by Schaffers) has been especially prepared for this occasion.

A new venture like the summer school organised in Acireale and the publication of an associated volume of readings requires a lot of patient and skilful secretarial hands (and minds). It is in this context that we gratefully acknowledge the contribution of Miss Rossana Chiara and Mrs. Lia Matarazzo to the organisation of the school. Ms. Dianne Biederberg skilfully and efficiently typed this manuscript, but not only that. In addition, she corrected the English of the manuscript and contributed in many other ways to the present form of the book. We very much appreciate her careful work. We are very grateful to Marianne Leutscher for all her secretarial assistance during both the organising of the school and the editing of this book.

Finally, we thank our wives for their patience and their assistance.

Günter Fandel
Benedetto Matarazzo
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The First International Summer School on MCDM

W. Matarazzo

1. The rapid development of the methods and techniques of Multiple Criteria Decision Making (MCDM) is reflected by a large number of applications in a wide variety of fields. The first studies on MCDM, carried out in the 1960s, ultimately led to a large number of research programmes being developed all over the world. Moreover, this was not merely a quantitative development, due to easily-aroused enthusiasm for a passing fashion. After a very short time, in fact, a number of results of primary importance were obtained, and new, extremely valuable paths of research were opened up.

As the most interesting of these studies were made public, the methods and problems of MCDM began to attract more and more attention from an ever-widening range of fields. Specialist groups of international experts were formed, (EURO working group on 'Aide à la Décision Multi-critère', and Special Interest Group on MCDM. These groups have continued to meet regularly, developing their research on the subject and providing opportunities both for group discussions of the results presented and for a valuable exchange of ideas and experiences between the various participants.

Apart from these groups, especially since the approbation accorded by the authorities and the undeniable success obtained, there is also a growing number of people who, for scientific, technical or professional reasons, would like to discover, or to know more about, certain aspects of MCDM. Today we can confidently say that MCDM has outgrown its early phase of development and reached full maturity.

In the light of this fact, some years ago a number of scholars began to consider the possibility of organising, in the form of a summer school, an advanced course in MCDM, which would take into account, as far as possible, the basic requirements of all the different fields. This approach, in spite of the difficulties and limitations arising

from the wide variety of subjects, and the ambitious nature of the objectives, seemed preferable to the organisation of a course at seminar level, dealing with specific aspects or a particular field of application of MCDM.

2. The idea was to deal with a variety of topics connected with MCDM, of both a general and a specific nature. Each topic was presented by one or more speakers, experts in that specific field, with the support of lecture notes and practical demonstrations with the computer. All the participants were continually encouraged to take an active part in the course, through critical group discussions, accounts of personal experiences and presentation of research data.

Owing to the large number of subjects to be discussed in a relatively short time (three periods of two hours daily for two weeks), many of the specialised topics and applications were discussed in parallel sessions. In view of this, once the specific problems of widest interest were established, the timetable of lectures and practical lessons on these subjects was programmed in such a way as to avoid clashes between two sessions on the same topic. In this way each participant was given the opportunity to organise his own course programme in the most suitable way, according to personal preferences and interests.

The main objectives of the Summer School were the following:

- To give a complete and up-to-date picture of MCDM problems, methods and software;
- To publicise results of the most recent theoretic and practical research;
- To encourage contacts between research workers of different countries and different education and background (universities, research centres, industries, government offices) and to promote a fruitful cooperation for the future, in the field of scientific research;
- To promote the application of MCDM methods, techniques and software in real-life operations, by informing and encouraging particularly active representatives of public and private concerns;
- To give each participant the opportunity to discuss real specific problems with experts, to the great advantage of the former (practical application of theoretic research, encouragement towards a deeper study of MCDM problems and methods, and towards the

organisation of special introductory courses to be held in their own companies); and of the latter (opportunities to check the practical possibilities of the MCDM methods proposed, and useful pointers for future research);

- To organise group discussions between research workers and practitioners in order to form a critical and comparative analysis of the methods and techniques suggested and to evaluate the available software.

3. In order to come as close as possible to the total achievement of these objectives, the Summer School was organised as a residential course, held in a quiet, comfortable hotel situated on a small bay of the Ionian coast near Catania. The aim was in fact, to render as easy as possible the contacts between teachers and participants, not only during the official 'lesson' periods, but also outside these. In this way, thanks to the utmost cooperation of the speakers, the fortnight's compulsory, but pleasant stay, was greatly instrumental in creating numerous opportunities for useful informal debates, and in giving rise to peaceful, but stimulating discussions, in a friendly atmosphere which was also partly responsible for the complete success of the Summer School.

Four personal computers and a terminal connected with a mainframe were established in one of the conference rooms of the hotel. These were used for practical demonstrations (software exhibitions) and were placed at the disposal of all the participants for the entire duration of the course. Moreover, to supplement the many papers and lecture notes distributed (about sixty), a small library was set up, where the participants could find some of the basic works published on the subject, together with bibliographical indications and information on further conferences and other initiatives connected with MCDM etc.

4. At a certain point, the organisers had some fear that the 'novelty' of the Summer School planned, the relatively long duration of the course and the distance of the site chosen from the main European capitals, would make the school less attractive. Fortunately, after a short time the large number of applicants for the course and requests for further information put an end to all fears. Evidently, the excellent qualifications of the lecturers, the outline of the programme, the suggested teaching methods, as well as the choice of Sicily, a land of enormous tourist and cultural attraction, had all contributed to arouse a widespread interest.

The participants, who came from sixteen different countries, were strongly motivated to maximise the 'take-home-value' of the course. For a variety of reasons, the group was extremely heterogeneous. First of all, the participants were not all in possession of the same university degree (Table 1): while 50 per cent of the participants had degrees in either mathematics or economics. In fact, a good 25 per cent had degrees in other subjects not directly concerned with careers generally associated with decision making. This fact can be considered

Table 1.

Division of Summer School Participants According to
University Degree

Degree	%
Mathematics	25
Economics	25
Engineering	12.5
Computer Science	10
Architecture	10
Political Science	5
Others	12.5
	<hr/> 100.0

in direct relation to the real motivation of those who took part in the Summer School. Many of the participants, in fact, were already well acquainted with the basic outline and methods of MCDM; they were therefore interested in either acquiring further knowledge, especially

Table 2.

Division of Summer School Participants According to
Profession

Profession	%
University professor	12.5
University research workers	37.5
Government employees	22.5
Industrial managers	7.5
Bank employees	7.5
Computer science consultants	7.5
Others	5.0
	<hr/> 100.0

with regard to specific formal-mathematical, technical or programming aspects - or in particular applications. Other participants, on the other hand, came into contact with MCDM for the first time at the Summer School; their aim was to get acquainted with the MCDM philosophy

and methods; alternatively, they were interested in the practical aspects of real-life operational applications in one specific sector.

The division of the participants according to profession (Table 2) also underlines the interest that the Summer School aroused in different fields. While 50 per cent of the participants were university professors or research workers (not only in mathematics or economic subjects, however) 35 per cent of them were professionally involved in considerable responsibility in decision making, either in government (22.5%), in banking (7.5%) or in industrial management (7.5%). Finally, 10 per cent of the participants were consultants, 75 per cent of them working in the field of computer science. The large number of participants connected with the world of economics leaves room for hope in a wider and more valuable cooperation in this field in years to come. These economists, through the acquisition of an adequate 'forma mentis' will be able to face problems of decision making in the future with a new and more suitable approach, an approach which will not only be valuable in the practical application of the different techniques acquired, but will also give them the opportunity to recognise and understand the true essence of real problems, and therefore to face them in the best possible way. And this, in our opinion, is already a first advantage of notable entity to be gained from the Summer School.

Of course, it is still too early to draw definite, or even provisional, conclusions on the results of this first Summer School. Once more, however, we wish to extend our warmest thanks to all the speakers for their generous and greatly appreciated cooperation, and to all the participants for their active interest. Together, with their comprehension, they helped us to solve all the new problems and unforeseen difficulties which arose unavoidably during the course. The experience acquired will certainly be of great value for a better organisation of similar enterprises in the future.

We feel justified, nevertheless, in expressing a decidedly positive verdict on this first Summer School, even if our judgement is based on the limited number of elements already at our disposal. The most valuable of these, as we have already said, is the enormous interest shown during the course by the participants, who worked continually with the utmost diligence and enthusiasm. Apart from attending all the lectures and practical lessons, they also asked the organisers on

several occasions to arrange for 'supplementary periods' in order to study and discuss further specific aspects of the subjects dealt with. The fact that the speakers placed themselves so willingly and so completely at their disposal, and the 'family' atmosphere which was immediately established at the Summer School, made it extremely easy to satisfy this, and other requests, greatly enriched the advantages to be drawn from the course.

Finally, we would like to underline that at the end of the course both speakers and participants expressed their desire for a periodic repetition of the initiative. We are particularly flattered by this choice, which clearly and eloquently expresses their approval and appreciation of the opportunities offered. We sincerely hope therefore that the First International Summer School of MCDM may really constitute the first link in a long chain of similar valuable initiatives, leading to better and better results, not only in the field of scientific research, but also in that of real-life applications. It is in this vein that we wish a lot of success to Jean Fichet and Philippe Vincke, the organisers of the second school.

1 Introduction: MCDM on Its Way to Maturity

G. Fandel and J. Spronk

Since its early development a few decades ago, MCDM has reached maturity but not in all respects. Many conferences are being held in east and west, in north and south. Many proceedings and special issues of important journals have appeared. Scholars and teachers all over the world are involved in research and teaching programmes of different size. Monographs, textbooks and dissertations have appeared in respectable numbers. Undoubtedly many more will follow. Furthermore, MCDM has received a lot of attention from practitioners both in the private and the public sectors. MCDM is used in practice to support actual decision processes. Nevertheless, MCDM has not yet reached full maturity. A still too large part of research in this field concentrates on algorithms rather than problems and, if problems are discussed, it is quite often as an illustration of these algorithms. This does not mean that this type of research is not needed. It does mean, however, that more effort should be directed towards problem oriented approaches. Fortunately, more and more research work is problem oriented. More attention is being paid to problem characteristics and to the adaptation of tools to problems instead of the other way round. In this respect, MCDM is still on its way to maturity. It is even so far as to be mature enough to marry. In our opinion, it is rather likely that MCDM will be coupled more and more with Decision Support Systems. The concern for problems and decision makers in DSS constitutes a fruitful land-stage for the attention for preferences in MCDM which, by its very nature, is also directed towards problems and decision makers. Such a marriage between MCDM and DSS will certainly benefit the stimulating results of recent research in psychology, organisation theory and game theory as far as they are concerned with the study of decisions by individuals and groups.

Research in the field of multiple criteria decision making is concerned with a number of different activities:

1. identification of decision alternatives;
2. generation and selection of solutions for decision problems with multiple criteria, involving only one decision maker;
3. generation and selection of solutions for decision problems with multiple criteria and several decision makers;
4. evaluation of the use of instruments designed to support decision makers confronted with multiple objectives in real applications.

(1) Studies dealing with the identification of decision alternatives focus on the question how the 'complete solution' of a decision problem with multiple objectives can be described and characterised. This 'complete solution' consists of the set of functionally-efficient decision alternatives and/or the set of efficient vectors of objective values. For linear problem structures, efforts have been made to describe and identify functionally-efficient facets of the set of alternatives by assigned preference cones of weights given to objectives. Extensions are concerned with the question to what extent available computational techniques which have already been applied to linear problem formulations are useful and/or must be modified for the determination of the set of efficient points in nonlinear problems. A third category of research work seems to be of particular interest from the point of view of economics. Apart from dealing with degeneracies of the set of alternatives, this type of research is among others, concerned with the question how nonessential objective functions can be identified and eliminated ex ante in order to simplify the decision problem. Here the nonessential objective functions of a criteria system are defined in such a way that their deletion will not modify the 'complete solution' of the decision problem at hand.

(2) Contributions which are concerned with the generation and selection of solutions for decision problems with multiple criteria involving only one decision maker, frequently assume some decision rule which serves as the decision maker's guiding principle. One can distinguish between multiple objective programming problems and the so-called multiattribute decision problems. The former are usually characterised by the fact that several objective functions are to be optimised with respect to an infinite convex set (implicitly described by a set of constraints) of decision alternatives. Multiattribute decision problems are concerned with the task of ordering a finite number of decision alternatives, each of which is explicitly described in terms of different characteristics (attributes) which have to be

taken into account simultaneously. The crux of the problem is in obtaining information on the decision maker's preferences. This can be achieved in many different ways. The spectrum ranges from directly asking the decision maker for preference statements on the basis of strong orders over preference functions, to the attempt to decompose a cardinal utility function with respect to its arguments in order to be able to measure the effects of isolated changes of individual objectives.

In a relatively large number of procedures, a linear or locally linear approximisable utility function is assumed. An optimal solution is then detected gradually by asking the decision maker for certain values of the objectives, for weights given to the objectives or for marginal rates of substitution between pairs of objectives. Some of these approaches attempt to improve or extend the available set of decision alternatives. Presently, much effort is devoted to the acceleration of algorithms for larger problems. Obviously, most efforts try to maintain the formal elegance of the algorithms and the comprehensibility of the solution process while avoiding that the information requirements become too heavy a burden for the decision maker.

A large part of research is devoted to sensitivity analyses. How sensitive is a given problem solution to changes in the input data? This question is not only important because of uncertainty with respect to the instruments and their effectiveness, but also because of uncertainty about the 'rightness' of the statements on the decision makers' preferences.

(3) In recent years, researchers have taken a particularly great interest in the field of group decisions and organisational decision processes. This has led to a series of publications with different methodical starting points. One group of papers tries to apply the concepts which have proven to be successful in dealing with multi-objective problems with one decision maker to problems involving a multiplicity of decision makers using the same analytical instruments. Another group of contributions in this field has chosen a completely different methodical starting point which so far has been of relatively little importance for decision theory with multiple objectives. Partly availing themselves of game and bargaining theoretic approaches, the authors examine under what conditions the former can be applied to multiobjective decision problems in groups.

In the first group one can encounter similar considerations on preferences structures as within the framework of multiattribute utility theory. Examples of questions which are dealt with are: which axioms allow the aggregation of the individual utility functions into a group preference function? How to solve the conflict between pareto-optimal and fair utility distributions among the group members. What forms of group preference functions or social welfare functions may be contemplated from this standpoint? In comparison with the first group, the game and bargaining theoretic approaches generally possess a greater formal elegance, having its basis in utility theory as well as in other axiomatic points of view. But it is just this fact which is often also regarded as a disadvantage of these approaches. Critics point out that the axiomatic foundation has a large influence on the determination of the optimal solution, which consequently entails the loss of flexibility required for practical applications. However, this critique is counterbalanced by the presence of a great number of game and bargaining theoretic solution approaches which are able to deal adequately with real decision behaviour as observed in groups and organisations.

(4) A steadily increasing number of studies is devoted to multiple criteria decision problems in fields as business administration, economics and the military. Applications include production allocation, research and development planning and problems of manpower allocation. Other studies are concerned with quality control problems of multilevel multiproduct manufacturing or with questions of public power supply, wage bargaining, transportation and location problems. Another main field consists of those studies dealing with resource allocation problems in university planning or with general educational planning. More and more of these studies concentrate on problem characteristics and on the question of how these characteristics condition the way a problem at hand can be solved and how much a solution process can be supported by using formal procedures. This is very different from earlier studies in which 'applications' are treated as illustrations of the potential of formal procedures.

Results of research in this area enter into an increasing number of courses both within and outside the universities. In line with this recent development, it was the aim of the First International Summer School on MCDM to give interested students, beginning academic researchers in fields as computer science, operational research and

management science and staff members in government and industry involved in planning and decision making, a state-of-the-art overview of multiple criteria decision methods, applications and software.

The first part of the summer school was devoted to the philosophy of multiple criteria decision making and to an overview of solution approaches for discrete problems. The second part was devoted to an evaluation of the usefulness of multiple criteria decision making in practice. This book contains selected readings of the summer school concerning methods and methodology (Part A) as well as applications (Part B).

The first paper in Part A by Jacquet-Lagrèze discusses 'Basic Concepts for Multicriteria Decision Support'. It describes concepts developed in very different research areas and their role in solving actual multiple criteria decision problems. The contribution 'Multiattribute Utility Theory as a Basic Approach' by Vincke starts with an overview of the three different directions in which multicriteria analysis has developed thus far: multiattribute utility theory, outranking relations or interactive methods respectively. Then basic concepts and principles of multiattribute utility theory are presented and methods of estimating utility functions will be discussed. The paper by Ostanello is especially devoted to 'Outranking Methods'. It is shown how outranking relations can be modelled and used within different problem formulations. After that, the outranking procedures of the ELECTRE type are characterised by their structures. In addition, flow charts of the ELECTRE procedures explain the course of selecting the best decision alternatives. Nijkamp/Voogd present 'An Informal Introduction to Multicriteria Evaluation'. A number of general evaluation issues in relation to public planning are dealt with regarding the feasibility and desirability of policy proposals. This paper is located at the cutting line between discrete and continuous multicriteria methods in so far as it gives an overview of methods of both categories. The contribution 'Multiple Criteria Mathematical Programming: an Overview and Several Approaches' by Zionts is designed as an introduction to continuous multiple criteria decision problems with a presentation of some of the methods that have been developed to solve the multiple objective mathematical programming problem. It defines and explores the relationship between objectives, constraints and related concepts and develops a typology of models. Naive methods of problem solving are analysed and it points out how the associated

ideas have been transformed into effective methods. In his contribution 'Mathematics of the Multiple Objective Problem - a Tutorial', Isermann starts with a general description of the multiple objective decision problem. He discusses the efficiency concept and the linear multiple objective programming problem. A solution method for linear programmes is outlined and illustrated by different numerical examples. Furthermore, this author describes procedures to find compromise solutions in case only limited information about the decision maker's valuation system is available. In the paper 'Decision Concepts for Organisations', Fandel shows that decision processes in organisations can be described as decision problems with several decision makers and different utility functions. Game and bargaining approaches are taken into account as solution methods. They are characterised by the actual decision rule which describes, or rather determines, the decision behaviour of the organisation members. Colson criticises in his paper 'Theories of Risk and MCDM' the traditional approaches to the risk concept which can be found in the literature, because of their lack of generality. Therefore, he proposes enlarging the concept of uncertainty, taking account of three basic uncertainty factors, hazard, ambiguity and complexity. The paper intends to show how MCDM literature can benefit from such a new analysis grid for uncertainty. Fichet starts in his paper 'Data Structures and Complexity of Algorithms for Discrete MCDM Methods' from the viewpoint that microcomputers will play an increasingly important part in the use of multiple criteria decision aid methods. Thus the time complexity of algorithms becomes of special interest. This time complexity is rather dependent on the data structure used to represent and to manipulate the objects involved in the algorithms. The paper illustrates this message for discrete MCDM problems. The contribution by Jelassi/Jarke/Checroun focusses on data management aspects of computerised decision support systems which use interactive multiple criteria decision methods. In this context the technical requirements for such systems and the importance of the data management tool to multiple criteria decision support systems are pointed out. Schaffers' paper 'Design of Computer Support for Multicriteria and Multiperson Decisions in Regional Water Resources Planning', the last contribution in Part A, deals with technical, psychological, ergonomic and organisational conditions for effectiveness of design and use of decision support systems for regional water resource projects. These projects show a high complexity due to many interrelations between aspects, decision makers and

planning procedures. A case study is used to discuss problems and opportunities in applying formal decision aids.

The applications in Part B begin with experiences in 'Financial Planning with Conflicting Objectives', reported by Spronk. He points out how financial planning problems become multiple criteria decision problems and gives an overview of different approaches to solve these planning problems. On the basis of a simplified case description, it is shown how these approaches may support the financial planning process. The second application oriented paper 'Interactive Multiple Goal Programming for Bank Portfolio Selection' by Spronk/Zambruno shows that goal programming approaches often proposed for bank portfolio selection possess some less desirable properties. An alternative approach is presented, circumventing these less desirable features while preserving the attractive properties of goal programming. This approach is illustrated by means of a simple example. In the paper 'MCDM Problems in Rabobank Nederland', Telgen describes two MCDM problems in a large organisation and also peculiar to the banking sector. The first problem concerns budgeting in which many different decision makers have conflicting objectives. The second problem is a bicriterion problem of bank balance sheet management. Both problems are tackled by non-standard methods; heuristic mathematical programming as well as graphic interaction are applied. The paper 'On the Applicability of Game-Theoretic and Bargaining Methods to a Wage Bargaining Problem' by Fandel reports on investigations concerning wage bargaining in the metal industry in the Federal Republic of Germany between 1961 and 1979. Formally, those processes may be treated as decision problems among two parties with different utility functions, so that solution methods of game and bargaining theory can be applied. In particular, the paper analyses the extent to which the methodical approaches of Nash, Zeuthen and Contini and Zionts can be used in practice in order to explain and reconstruct the course of and the agreements within wage bargaining processes. Fichet starts in his contribution 'Computer Selection and Multicriteria Decision Aid' with the statement that computer selection is obviously a decision problem with multiple objectives. Scoring methods based on a value function are often used as a tool to tackle the computer selection problem. Given the complexity of the latter problem, the use of these scoring methods can be criticised from many points of view. The purpose of the paper is to show that decision aid models based on the ELECTRE approaches may be better suited to solving these decision problems in