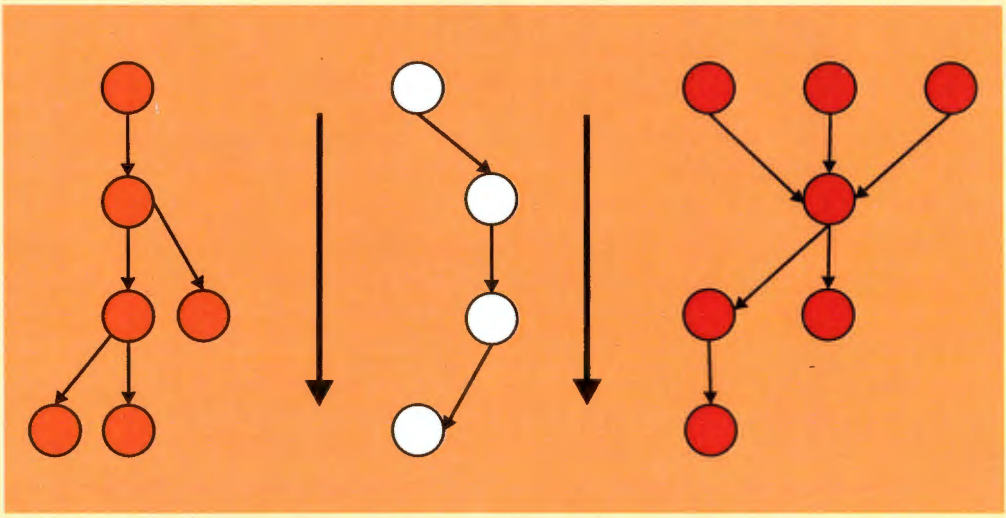
SYSTEMS RESEARCH INSTITUTE
POLISH ACADEMY OF SCIENCES

MULTICRITERIA ORDERING AND RANKING:
PARTIAL ORDERS, AMBIGUITIES AND APPLIED ISSUES



Jan W. Owsiński and Rainer Brüggemann
Editors

Warsaw 2008

SYSTEMS RESEARCH INSTITUTE
POLISH ACADEMY OF SCIENCES

MULTICRITERIA ORDERING AND RANKING:
PARTIAL ORDERS, AMBIGUITIES AND APPLIED ISSUES

Jan W.Owsiński and Rainer Brüggemann
Editors

Warsaw 2008

This book is the outcome of the international workshop held in Warsaw in October 2008 within the premises of the Systems Research Institute. All papers were refereed and underwent appropriate modification in order to appear in the volume. The views contained in the papers are, however, not necessarily those officially held by the respective institutions involved, especially the Systems Research Institute of the Polish Academy of Sciences.

ISBN 83-894-7521-9
EAN 9788389475213

Technical editing and typesetting:
Jan W.Owsiński, Anna Gostyńska, Aneta M.Pielak

Pragmatic Issues in Business and Administration

Multicriteria Ordering and Ranking: Partial Orders, Ambiguities and Applied Issues
Jan W. Owsiński and Rainer Brüggemann, Editors

Some Experiences with a Group Multicriteria Method for Project Evaluation

Lech KRUŚ

Systems Research Institute, Polish Academy of Sciences,
Newelska 6, 01-447 Warsaw, Poland (krus@ibsoan.waw.pl)

A case study dealing with allocation of EU structural funds in the capital region of Mazovia in Poland is presented. A new method supporting multicriteria analysis and selection of projects applying for the funds has been proposed and used in the study. According to the method an interactive procedure has been implemented in which a group of experts formulates the multicriteria decision making problem, carries out an analysis of the projects, and finally creates a ranking of the projects. Experiences from the case study are presented.

Keywords: multicriteria analysis, group methods, computer-based support

1. Introduction

The structural funds of the European Union are the financial instruments by means of which the policy for support of multi-dimensional development, enhancement of economic and social cohesion, reducing differences of regional development standards and restructuring and modernizing the economies of those member states whose development level is below the average development level in the European Union is implemented.

In the 2007–2013 programming perspective Poland may take advantage of the support within the framework of the following structural funds: the European Regional Development Fund (ERDF), the European Social Fund (ESF), the Cohesion Fund, the European Agricultural Fund for Rural Development (EAFRD), and the European Fisheries Fund (EFF).

The European Regional Development Fund (ERDF) is meant for financing undertakings in the regions with the development level substantially lagging behind the average for the EU, as well as in the regions with major restructuring activities

in industry and employment. The funds are addressed particularly to financing investment in infrastructure and environmental protection, development of small and medium enterprises, creation of new jobs through investment in manufacturing, research and development activities. Potential beneficiaries are territorial self-government units, their unions and associations, entrepreneurs (small and medium), government administration bodies, national and landscape parks, National Forestry and its organizational units, R&D units, (other) units of the public finance sector with legal entity, non-governmental organizations, business support institutions, housing associations and housing cooperatives, as well as water law companies.

Utilization of the ERDF is coordinated in Poland by the Ministry of Regional Development. It is done according to the documents like the National Development Strategy (NDS) for Poland, the National Strategic Reference Framework, and the National Cohesion Strategy adopted by the EU Commission. The Ministry allocates the funds among regions – provinces being administrative units, called voivodships in Poland. The funds are allocated among beneficiaries on the regional level by the self-governments of voivodships within the Regional Operational Programs (ROP), negotiated and approved by the EU Commission. The Ministry, having the consent of the EU Commission, decided that the most important projects for regional development (called key projects) can be submitted and co-financed within the ROP before standard competitions for other projects will start.

The paper deals with the Regional Operational Program (ROP) of the capital Mazovian Voivodship for the years 2007-2013. A case study has been organized to support selection of the key projects from a list of projects submitted. The paper describes experiences from the case study.

A new multicriteria, group method supporting analysis, assessment and selection of the key projects has been proposed and implemented within the study. The method enables valuation and ranking of projects on the basis of assessments made by a group of independent experts. The method includes full procedure of activities of the experts, starting from a formal definition of the multicriteria decision making problem, analysis of hierarchical objectives, specification of criteria and acceptability conditions for the projects submitted, valuation of the projects on the base of individual assessments, ranking and selection of the projects most essential for the development of the region. The method has been implemented in the form of series of panel sessions in which experts were supported by a computer-based system. Different group techniques have been applied like brainstorming, the Delphi method, and the cardinal assessment approach.

2. Multiobjective decision problem

The case study has started from the formulation of the multiobjective decision problem. The proper formulation of the problem requires specification of the following key components:

- Decision making unit. It is the main decision maker with a collection of men and machines acting as an information processor and generating the decision.
- Set of objectives and their hierarchy. The objective defines the state of the system required by the decision maker.
- Set of criteria (attributes) and relations objectives – criteria. Values of the criteria measure the degrees of attainment of the objectives.
- Decision situation. It includes the specification of input information required and accessible, decision environment and state of nature, set of alternatives, constraints, decision variables, relations: decision variables – criteria.
- Decision rule. The rule includes processing of the input information, analysis, value judgment, decision generation and implementation.

These elements were considered and specified during the case study.

The Self-Government of the Mazovian Voivodship announced in 2006 the competition for the key projects co-financed from the EU structural funds within the Regional Operational Program of the voivodship for 2007-2013. More than 150 projects applied for the competition. The list of the key projects had to be prepared together with the respective justification. The projects not qualified as the key projects could apply again in the standard competitions organized at a later time.

The decision unit was the Board of the Self-Government of the Mazovian Voivodship, responsible for the final decision. The decision was prepared by the Department of Strategy and Regional Development of Board and by the Mazovian Bureau for Regional Development.

2.1. Specification of objectives

The meaning of the "key projects" had to be specified first as the basis for the formulation of objectives. The working team has been organized consisting of experts from the Department of the Strategy and Regional Development of the

Government, experts from the Mazovian Bureau for Regional Planning in Warsaw and an adviser responsible for group multicriteria decision support. Working sessions were organized in which the "brainstorming" technique was used (Hwang, Lin, 1987; Osborn, 1963). The technique enables free and unlimited presentation of proposals but with strictly defined rules of analysis end evaluation of the proposals.

The team of experts decided that as the key projects - such projects should be selected, which substantially realize the directions of the activities specified in the development strategy of the province, taking into account: the directions of the spatial management defined in the spatial plan of the province, the competitiveness of the province in the international and the national context, the effects of synergy with other socio-economic spheres, and the innovativeness. The acceptability conditions were specified. The projects that do not produce the effects of the structural, socio economic and the spatial change in the region, or belong to other operational programs or have local character or do not fulfill the objectives of the Regional Operational Program for 2007-2013, should be rejected.

2.2 Input information, documents

The main objectives of the cohesion policy, taking into account the socio-economic conditions in Poland, are included in the document entitled "National Strategic Reference Framework for 2007-2013". The document elaborated according to the EU directives defines support directions from funding available from the EU budget in the forthcoming seven years within the European Regional Development Fund and the Cohesion Fund. It is a reference instrument for development of operational programs. According to the document the regional development programs were elaborated, negotiated and adopted by the EU Commission. In the voivodships there are also other documents prepared, like development strategies, spatial management plans and others.

The team analysed respective documents and decided that the assessment of projects should be made according to the objectives and the directions of activities given in the Development Strategy of the Mazovia Province till 2020, according to the objectives and priorities of the Regional Operational Program of the voivodship for 2007-2013, and to the specifications given in the Plan of Spatial Management of the Mazovia Province. The documents as well as the application questionnaires created the information base for the project assessment.

2.3. Features of the decision problem

It was found that the set of the objectives, which should be taken into account, is really complex. The Development Strategy of the Province till 2020 presents a hierarchical system including an overall objective, strategic and indirect objectives, directions of activities. The Regional Operational Program (ROP) for 2007-2013 includes also a hierarchical set of objectives, priorities and directions of activities. The criteria respective to the objectives have qualitative character. The projects submitted within the different priorities are hardly comparable.

It was found that the information included in the existing questionnaires is very limited. These questionnaires were elaborated earlier.

The decision had to be prepared in a very short time. The entire process, including preparation of the method, organization of the interactive sessions, assessment of all the projects, derivation of the ranking and the final list of the key projects had to be conducted in 10 days. The team had no earlier experience in such a work.

3. Analysis of objectives and specification of criteria

3.1 Specification of objectives and criteria

The experts have been informed how they should understand the meaning of objectives and criteria. The objective defines the required state of the system that the DM would like to achieve. The criteria specified for an objective measure on a numerical scale the degree, to which the objective is achieved. For each objective one or several criteria have to be specified. Criteria should fulfill the following requirements (see Keeney, Raiffa, 1976). The values of the criteria should define in a unique and sufficient way the achievement level of the respective objective. Each criterion should be comprehensive and measurable. A set of criteria should be:

- complete, i.e. all pertinent aspects of the decision problem are represented by criteria,

- operational, i.e. it can be utilized in some meaningful manner in the ensuing analysis,

- decomposable, i.e. simplification of the valuation process is possible by disaggregating the decision process into parts,

- not redundant, i.e. no aspect of the decision problem is accounted for (by criteria) more than once,

- minimal – there is no other complete set of criteria representing the same problem with a smaller number of elements.

3.2 Criteria specified by experts

An interactive multi-round session has been organized in which experts worked according to the "brainstorming" technique. The objectives have been analyzed one by one. Proposals of criteria have been generated for each objective accompanied by respective motivations. The requirements presented above have been checked as well as accessibility of information from the application questionnaires. Finally, after analysis and discussion of all the objectives and their hierarchy, the following set of criteria has been specified, unanimously accepted by all the experts:

K1. The degree of realization of the activity directions specified in the development strategy and in the spatial plan of the voivodship.

K2. The influence of the project on the competitiveness of the voivodship in the national and international context.

K3. Effects of synergy with other socio-economic spheres.

K4. Innovativeness of the project.

4. Project valuation and ranking

An original method extending the cardinal approach described in (Hwang, Yoon, 1981) has been proposed to the experts. It enables the group, multicriteria judgment of projects in the case of qualitative criteria. The interval scale is fixed for each criterion. Experts evaluate projects assigning values for criteria using the scales. The Delphi method is applied to set the interval scales. The expert's evaluations are discussed, corrected and set with use of the Delphi method. Each project is represented by a point in the space of criteria K1–K4. Experts are asked to define the hypothetical ideal key project and the respective point in the multicriteria space. The ranking of projects is based on the distance to the ideal point. Different ways of measuring the distance, compared also to the classical weight method have been proposed to the experts.

4.1. Idea of the method

We assume that experts have equal power and their evaluations have equal importance. Each expert evaluates each criterion for a given project by proposing a value from a given scale interval. Values given by experts are normalized. Let n be

the number of experts, m – the number of evaluated projects, p – the number of criteria. The following steps are performed.

Step 1

Each expert k assigns a value a^k_{ij} to the project i for the criterion j. The normalized individual values are calculated:

$$d_{ij}^k = a_{ij}^k / \sqrt{\sum_{i=1}^{m} (a_{ij}^k)^2} \text{ , where } k=1..n,\ i=1,..,m,\ j=1,..,p.$$

The vales are aggregated in the matrix

$$C = [c_{ij}] = \sum_{k=1}^{n} d_{ij}^k / n .$$

A vector criteria of weights is given: $W=\{w_1,..,w_p\}$, such that $\sum_{j=1,...,p} w_j = 1$.

The collective values are derived in the matrix

$F=[f_{ij}]=[c_{ij}w_j]$, $i=1,..,m, j=1,..,p$.

Step 2

The hypothetical best, ideal project as well as the worst one, are fixed. Let c_{ij} be the aggregated value for a criterion j of a project I, and J be set of all criteria. The artificial ideal project is defined (for the maximized criteria) by:

$$A^* = \{(\max_i f_{ij} | j \in J\} = \{f^*_1,..f^*_p\},$$

where the maximization is made with respect to all projects, and the artificial worst, „nadir" project, is defined by:

$$A^- = \{(\min_i f_{ij} | j \in J\} = \{f^-_1,..f^-_p\}$$

Step 3

The importance ("value") of each project is derived on the basis of the distance between this project and the ideal one. The distance can be measured in different ways. Three measures have been proposed to the experts and then considered by them.

The distance measured according to the norm l_1:

$$s_{i1} = \sum_{j=1}^{p} | f^*_j - f_{ij} |, \text{ where } i = 1,...m, \quad (1)$$

- according to the Euclidean norm l_2:

$$s_{i1} = \sum_{j=1}^{p} | f^*_j - f_{ij} |, \quad (2)$$

- according to the Chebyshev norm l_∞:

$$s_{i\infty} = \max (|f^*_1 - f_{i1}|,...,|f^*_p - f_{ip}|). \quad (3)$$

Step 4

The distance of a project i to the ideal one is normalized to the 100-points scale.

$$G_i = 100 \times (1 - s_i/s), \quad 0 < G_i < 100, \; i = 1,..m, \quad (5)$$

where s is the distance of the point A^- (nadir) to the ideal point A^*. The greater G_i means that the project i is better. The project equivalent to the ideal one gets 100 points, while the worst one - 0 points. It can be shown that in the considered case the valuation of projects derived with the use of distance to the ideal point measured according to the norm l_1 coincides with the valuation obtained by the classical methods of weights.

4.2. Implementation

In the first stage of implementation the experts had to analyze the logical relations of the criteria, to set the weights assigned to the criteria and to set the interval scales. The modified version of the Delphi method was applied. The original Delphi method has been elaborated in the Rand Corporation, see Linston, Turoof (1977). In the implemented version, the work of the group of experts was organized in the form of multi-round interactive sessions. In the consecutive rounds experts' proposals were presented together with respective argumentation. The proposals were jointly analyzed and discussed, especially in the case of divergent evaluations. On this basis each expert could correct his opinion in the next round taking into account the arguments of other experts.

The weights assigned to the criteria have been fixed as follows: K1: 50%, K2: 20%, K3: 20%, K4: 10%. The experts agreed to take the scale of 10 points for each criterion. The first criterion was divided into two subcriteria: K1a - degree of realization of the activity directions defined in the development strategy of the province (assessed on the scale of 0-7 points), and K1b - degree of realization of the directions of the spatial management defined in the spatial plan of the province (0-3 points). The experts decided that these sub-criteria are additive.

The experts initially evaluated several projects. The different rankings of the projects according to the norms (1), (2), (3) and according to the classical weights method were derived and presented to the experts. Figs. 1, 2, 3 illustrate the ways of ranking. The set of projects is shown in each figure as a set of points in the space of two weighted criteria. The ideal as well as the "nadir" points are shown. The continuous lines represent sets of projects being at the same distance to the ideal point i.e. being in the same position in the ranking.

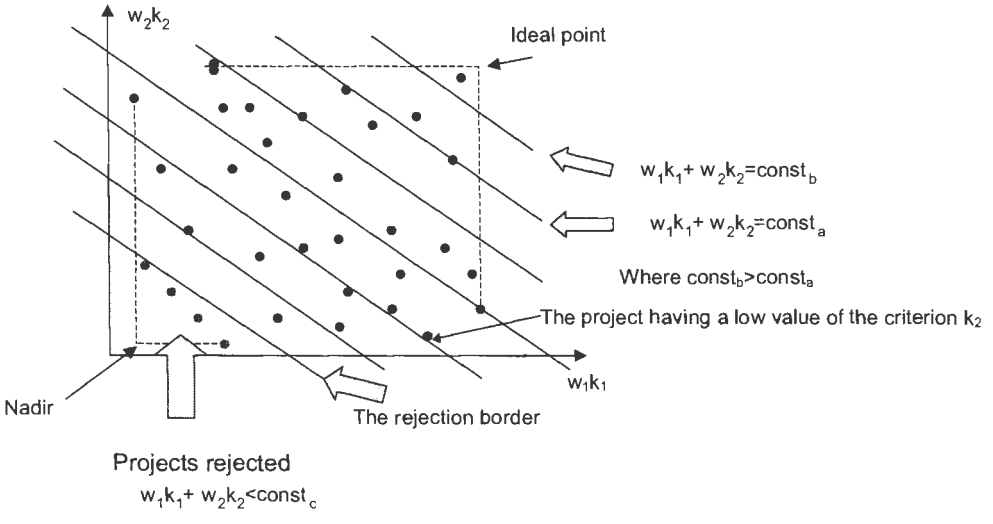


Figure 1. The valuation and ranking of projects according to the classical weight method

The classical method of weights is shown in Fig. 1. Selection of the key projects means that a border line of distance to the ideal point has to be assumed. The projects below the line are rejected. Our real problem is considered in the four

dimensional space. The border is defined in this case by a hyperplane. The weight method is very popular and traditionally applied in practice due to its simplicity and practicality. The question arises: Does it really reflect the preferences of experts? Let us see the project having a low value of the criterion k_2 and a very high value of the other criterion (the project in question is indicated in Fig. 1). This project would be in the ranking higher than projects having balanced values of all criteria. Is it really correct according to the feeling of experts? The weight method is justified if the criteria are additive. In general, the description of experts' preferences may be nonlinear. The rankings derived with use of the norm l_2 and $l\infty$ serve as examples of such nonlinear descriptions of the preferences. Of course, use of other nonlinear descriptions is possible.

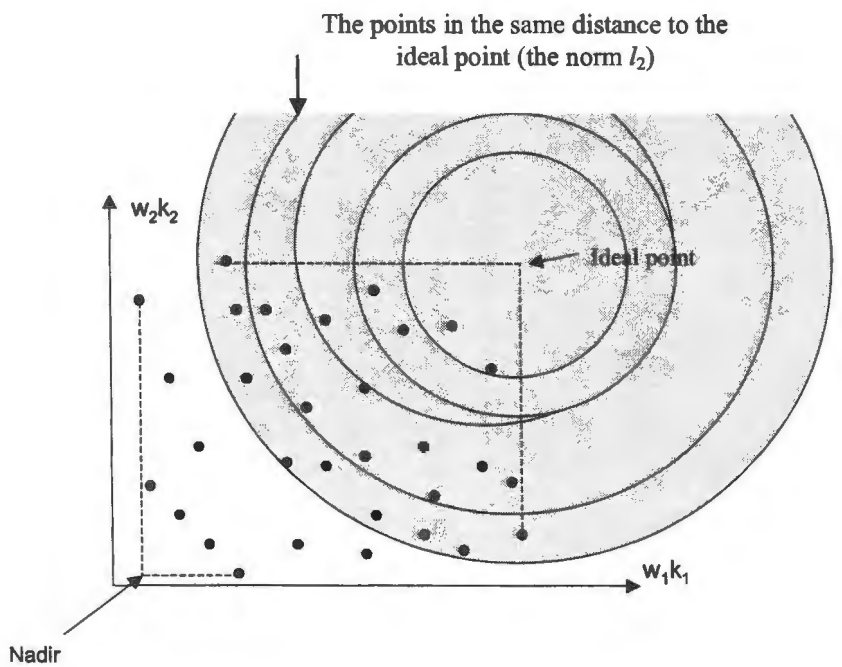


Figure 2. The valuation and ranking of projects according to the distance to the ideal point (the distance measured by the Euclidean norm l_2)

The experts decided that the key projects should be selected using the Euclidean norm. The rankings defined with use of the norm l_∞ and by the weight method were derived for the sake of comparison.

In practice, in typical implementations, each project is assessed by 5-7 or a bigger number of experts. Having the values given by experts, the extreme values are rejected and the mean value is derived as the collective one. In the considered case study the time for the entire procedure was very limited. All the projects had to be analyzed and valuated in a few days. The team of experts consisted of 7 specialists. In the applied solution each project was analyzed and assessed independently by the experts from the Department for the Strategy and Regional Development of the Self-Government and from the Bureau for the Regional Planning of the Mazovian Voivodship.

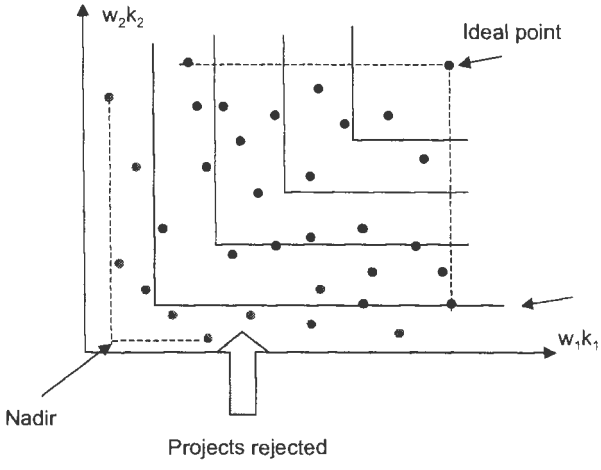


Figure 3. The valuation and ranking of projects according to the distance to the ideal point (the distance measured by the norm $l\infty$)

The experts checked whether a given project satisfied acceptability conditions mentioned in Section 2.1, and if so, made the assessment according to the assumed set of criteria. The assessments were treated as introductory. The special interactive session was organized after the individual assessments had been made. In the session, the projects and the introductory opinions were analyzed again by all the experts, especially in the case of divergent introductory opinions. The opinions

could be corrected after the discussion and the negotiation of arguments according to the Delphi method. The experts were supported during the session by a computer-based system.

The system takes as inputs the experts' opinions. On this basis it produces valuation of projects, derives the distance of each project to the ideal point according to the assumed Euclidean norm, and also according to the l_1 and $l\infty$ norms. It generates the respective ranking lists. The system works in an interactive way. Experts can on line correct their opinions, obtain corrected results, analyze project valuations and observe changes in the ranking lists.

The resulting list of the key projects established and approved by the team of experts, and the ranking list of all the projects have been presented and recommended to the Board of the Self-Government of the Mazovian Voivodship. On the basis of the list and the opinions of the experts, the indicative investment plan has been elaborated and accepted by the Board of the Self-Government of Mazovia. The list of the key project is presented on the website of the Self-Government.

5. Conclusions

An original, specially prepared group, multicriteria method has been applied to make the ranking and selection of the key projects. The ideas of different approaches have been used including the brainstorming techniques, the Delphi method and the extended cardinal approach to the group multicriteria decision making. To make the ranking, the positions of the projects in the multidimensional space of criteria are analyzed. On the basis of the experts' opinions the distance of each project to the ideal key project is derived. The projects closest to the ideal one are selected as the key projects. It has been found that the experts comparing several different measures of distance have not selected the classical weight method but the nonlinear measure based on the Euclidean norm.

The weight method, frequently used, is justified under the assumption that all criteria are additive in the preference relation. In general, the assumption can be not fulfilled, but in practical implementations it is frequently even not checked.

In this case study the experts could make a choice. They did not approve the weight method, but selected and approved non linear description of their preferences according to the Euclidean norm for measuring the distance of each project to the ideal „key" project.

The method has been elaborated and implemented at the commission from the Mazovian Bureau for Regional Planning in Warsaw (Krus, 2006a). The final list of the selected key project was the basis for the indicative investment plan elaborated and accepted by the Board of the Self-Government of the Mazovia Voivodship.

References

Bury H., Wagner D. (2007) Determining group judgment when ties can occur. In: *Proc. of 13th IEEE IFAC International Conference on Methods and Models in Automation and Robotics MMAR 2007*, Szczecin, Poland, 779-784.

Development Strategy of the Mazovian Province till 2020 (2006) Mazovian Bureau for Regional Planning in Warsaw, Warszawa http://www.mazovia.pl/?a=news&id=2342

Hwang C.L., Lin M.J. (1987) *Group Decision Making under Multiple Criteria.* Springer Verlag, Berlin/New York.

Hwang C.L. Yoon K. (1981) *Multiple Attribute Decision Making Methods and Applications. A State of Art Survey*. Springer Verlag, Berlin/Heidelberg/New York.

Keeney R.L., Raiffa H. (1976) *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*. John Wiley & Sons Inc., New York.

Kruś L. (1996) Multicriteria Decision Support in Negotiations. *Control and Cybernetics*, **25**, 6, 1245-1260.

Kruś L. (2004). A Computer Based System Supporting Analysis of Cooperative Strategies. In: L. Rutkowski, J. Siekmann, R. Tadeusiewicz, L. Zadeh, eds, *Artificial Intelligence and Soft Computing – ICAISC 2004. Lecture Notes in Computer Science*, Springer Verlag.

Kruś L. (2006a) A Method of Group, Multicriteria Evaluation of Regional Projects from the Point of View of their Importance for Development of the Mazovian Voivodship (Metoda grupowej, wielokryterialnej oceny projektów regionalnych z punktu widzenia ich istotności dla województwa mazowieckiego). Expert's Report commissioned by the Mazovian Bureau for Regional Planning in Warsaw, Warszawa. (in Polish).

Kruś L. (2006b) Supporting multicriteria decisions. Master Course Lectures. Warsaw School of Information Technology, Warsaw.

Lewis A.C., Sadasky T.L., Connoly T. (1975) The Effectiveness of Group Brainstorming in Engineering Problem Solving. *IEEE Trans. On Engineering Management*, **EM-22**, 3, 119-124.

Linstone H.A., Turoof M. (1977) *The Delphi Method, Techniques and Applications.* Addison Wesley, Reading, Massachusetts.

National Development Strategy (NDS) 2007-2015 for Poland (2006) Ministry of Regional Development, Poland.

National Cohesion Strategy (NCS) 2007 –2013 (2006) Ministry of Regional Development, Poland.

National Strategic Reference Framework for 2007-2013 (2007) Ministry of Regional Development, Poland, 2007, http://www.mrr.gov.pl/NR/rdonlyres/A1A61D68-4528-499F-9199-5FE0E0533F0D/31941/NSRO_maj2007.pdf, Warszawa.

Osborn A.F. (1963) *Applied Imagination.* Charles Scribner Sons, New York, 3rd ed.

Plan of Spatial Management of the Mazovia Province (2004) Mazovian Bureau for Regional Planning in Warsaw, http://www.mbpr.pl/, Warszawa.

Regional Operational Program for the Mazovia Province 2007 – 2013 (2008) Local Government of the Mazovian Voivodship, Warszawa http://www.mazovia.pl/?a=rpo_wm.

This book is a collection of papers, prepared in connection with the 8th International Workshop on partial orders, their theoretical and applied developments, which took place in Warsaw, at the Systems Research Institute, in October 2008. The papers deal with software developments (PYHASSE and other existing software), theoretical problems of ranking and ordering under various assumed analytic and decision-making-oriented conditions, as well as experimental studies and down-to-earth pragmatic questions.

ISBN 83-894-7521-9
EAN 9788389475213