

Multiple Criteria Decision Making

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Intelligent Decision Support Systems

Combining Operations Research and
Artificial Intelligence - Essays in Honor
of Roman Słowiński



Springer

Multiple Criteria Decision Making

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Constantin Zopounidis, School of Production Engineering and Management,
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Salvatore Greco • Vincent Mousseau •
Jerzy Stefanowski • Constantin Zopounidis
Editors

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and Artificial Intelligence - Essays in Honor
of Roman Słowiński

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Preface

This special collective book is dedicated to Professor Roman Słowiński on the occasion of his 70th birthday this year—2022.

Professor Roman Słowiński (Fig. 1) is a widely recognized scientist due to his work in the fields of operations research, multiple-criteria decision-making, optimization, computer science and artificial intelligence. In particular, he strongly participated in the creation and development of the domain of intelligent decision support systems, which combines elements of operations research and artificial intelligence. This research thread became the leading idea of this book and the inspiration for its title.

In his long-term scientific career, which began at the Poznań University of Technology in 1974, Roman Słowiński undertook various thematically basic theoretical and applied research. This is reflected in more than several hundred published scientific texts that are well appreciated in the international research community, which is visible by the very high number of citations, and on this basis, Roman Słowiński is among the world's highest-cited researchers in computer science and operations research, occupying the first position in Poland.

Professor Roman Słowiński is an authority, mentor, and inspiration for many researchers all over the world. He opened the door to real scholarship to many people, including us.

He actively participated in international collaborations. The number of his co-authors, many of them from outside Poland, exceeds 150. Throughout his career, he has been visiting professor or researcher at many well-known universities. He has participated in many conferences and has been invited several times to give keynote speeches. We illustrate this with the attached photos (Figs. 2, 3, 4 and 5).

In addition to his position as a university professor and researcher, he served in a number of organizational capacities. In particular, he is the vice president of the Polish Academy of Science. For many years, he has also served as one of the editors-



Fig. 1 Professor Roman Słowiński



Fig. 2 Roman Słowiński together with Salvatore Greco, Constantin Zopounidis, and Pekka Korhonen during 22nd Conference of the International Society on Multiple Criteria Decision Making, June 17–21, 2013, Malaga, Spain

in-chief of the well-known scientific journal—the European Journal of Operational Research. It is also worth emphasizing that in the 1990s, he founded the Intelligent Decision Support Systems lab at Poznań University of Technology, which he has led until now.

Let us also mention that he has been awarded several times for his extraordinary achievements with various prestigious recognitions, both in Poland and in the international research societies or universities.



Fig. 3 Bernard Roy and Roman Słowiński in Poznań in 1992



Fig. 4 Roman Słowiński, on the right, together with (from the left to the right) Jerzy Stefanowski, Shusaku Tsumoto, Lofti Zadeh, Wojciech Ziarko and Zdzisław Pawlak during 4th Int. Workshop on Rough Sets, Fuzzy Sets and Machine Discovery, Tokyo, 1996



Fig. 5 Jerzy Stefanowski, Benedetto Matarazzo, Jan Weglarz, Roman Słowiński and Jerzy Stefanowski during EURO XVI Conference in Brussels, 1998

In the first chapter of this volume, following this preface, we present in more detail main research contributions of Roman Słowiński, so we will not repeat it now. Furthermore, the second chapter also contains more information on his scientific biography.

This book contains 21 chapters written by several of Roman Słowiński's collaborators, his previous PhD students, and friends, which cover various issues related to his research interests and contributions to such fields as multiple criteria decision aiding, multi-objective optimization methods, intelligent decision support systems, and uncertainty managing in artificial intelligence. These chapters also well demonstrate Roman Słowiński's influence on theory and practice of intelligent decision support systems, and we hope that the readers could find them stimulating and enjoyable.

Finally, we know that Roman Słowiński will continue to be a very active scientist in the next years. We wish him many more successes and happy years of health, with his family and in our community.

Catania, Italy
Gif sur Yvette, France
Poznan, Poland
Chania, Greece

Salvatore Greco
Vincent Mousseau
Jerzy Stefanowski
Constantin Zopounidis

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Chapter 1

Roman Słowiński and His Research Program: Intelligent Decision Support Systems Between Operations Research and Artificial Intelligence



Salvatore Greco, Vincent Mousseau, Jerzy Stefanowski,
and Constantin Zopounidis

Abstract This chapter is aimed to present the genesis and the development of the scientific research activity of Roman Słowiński considering his contributions in Operations Research, Multiple Criteria Decision Aiding, and Artificial Intelligence in the perspective of Intelligent Decision Support Systems. We try to reproduce his vision of intelligent decision support systems, which he largely initiated in the scientific community, and his ideas and achievements in this field. The impact of his contacts and collaborations with other researchers was also important in creating the field. On the one hand, it was formed on the interaction with three great scientific personalities such as Jan Węglarz, Bernard Roy, and Zdzisław Pawlak, and on the other hand, it was developed during the years with a very large and diversified network of cooperators from his own University as well as from other research teams distributed in many different countries. In addition, we provide an in-depth bibliometric analysis of Roman Słowiński's published papers. We introduce also

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the contributions of this book discussing their relation with the work of Roman Słowiński.

1.1 Introduction

This volume is a Festschrift in honor of Roman Słowiński for his 70th birthday. Roman Słowiński is one of the most influential scholars in the fields of Computer Science, Operations Research, Artificial Intelligence, and Decision Science over the last forty years. Through the contributions of some of the many colleagues that along the years have been cooperating and interacting with him, this volume aims to shed light, on the whole life scientific project of Roman Słowiński: combining Operations Research and Artificial Intelligence into Intelligent Decision Support Systems.

The basic idea of Intelligent Decision Support System is often acknowledged to the early contribution of Herbert Simon [88, 90], one of the fathers of Artificial Intelligence and 1978 Nobel Prize for Economics, that proposed to integrate intelligent capabilities in decision support systems (for a general reconstruction of Herbert Simon's contribution to decision support systems see, e.g., [80]). In one illuminating paper [89], considering the widespread interest in expert system at the end of the 80s due to the availability of minicomputers manifested in those years, Herbert Simon discussed about combination of Artificial Intelligence (AI) and Operations Research (OR), proposing "to think of expert systems and the data bases that support them as matrices within which we can apply an amalgamation of AI and OR analytic and problem-solving methods." More precisely, after observing that "in the decade after 1955, the tools of AI were applied side by side with OR tools to problems of management" and that "after about 1960, AI and OR went their separate ways," Herbert Simon proposed what can be seen as his vision for intelligent decision support systems: "We should aspire to increase the impact of MS/OR [Management Science/Operations Research] by incorporating the AI kit of tools that can be applied to ill-structured, knowledge-rich, nonquantitative decision domains that characterize the work of top management and that characterize the great policy decisions that face our society." In the program drafted by Herbert Simon we could notice the inspirations for the agenda developed in his almost fifty years of scientific activity by Roman Słowiński, even if we were not able to find a single citation of that paper in the 14 books and more than 400 articles published by him. Consequently, it is interesting to reconstruct how Herbert Simon's vision became the scientific program of Roman Słowiński through his meeting, acquaintance, collaboration, and friendship with three scholars who shaped operations research, decision aiding, and computer science: Jan Węglarz, Bernard Roy, and Zdzisław Pawlak.

Jan Węglarz, who was a teacher and the supervisor for the master thesis and the PhD of Roman Słowiński at the Poznań University of Technology, introduced him to OR and, in particular, to project scheduling. The results obtained by Roman Słowiński in this domain, some of them together with Jan Węglarz, were so strikingly relevant and innovative that Roman Słowiński and Jan Węglarz, together

with Jacek Błażewicz, another brilliant student of Jan Węglarz, were awarded with 1991 EURO Gold medal, the highest distinction within OR in Europe. Observe that EURO Gold medal is in general considered as the award of a lifelong research activity and Roman Słowiński got this prize when he was still not forty years old. In fact, project scheduling was for him an excellent starting point rather than a point of arrival. From the point of view of intelligent decision support systems, starting from project scheduling had two positive aspects for Roman Słowiński:

1. Scheduling with its use of heuristics, as recognized by Herbert Simon in the above mentioned article, was one of the few domains in which, application of AI continued to be coupled with OR even when the trajectories of AI and OR diverged; in this perspective, the first years of research activity shaped the mindset of Roman Słowiński to work on intelligent decision support systems (and, in fact, one of his last papers on scheduling was proposing a decision support system for applications in that domain [100]);
2. Research on scheduling permitted to meet Bernard Roy, one of the founders of OR in Europe, that introduced Roman Słowiński to multiple criteria decision aiding, probably the domain in which he devoted most of his efforts and capacities.

Roman Słowiński met Bernard Roy in 1977, participating, together with Jan Węglarz, at the congress of Association Française pour la Cybernétique, Économique et Technique (AFCET). Bernard Roy was interested in the presentation of Roman Słowiński and wanted to speak with him. This was the beginning of a scientific cooperation and a sincere friendship of the two researchers developed for forty years until the death of Bernard Roy. Let us remember that Bernard Roy, one of the major promoters of OR techniques in Europe, gave fundamental contributions in graph theory and scheduling, but, overall, he is the founder of the European School of Multiple Criteria Decision Aiding (MCDA), proposing, beyond the famous ELECTRE methods, many important contributions to the overall approach and the scientific foundation of MCDA. The basic reference in MCDA is the Bernard Roy's book "Méthodologie multicritère d'aide à la décision" [82] that Roman Słowiński translated in Polish [84]. To synthesize the basic idea of MCDA promoted by Bernard Roy we can consider the following frame, taken by a paper written together with Roman Słowiński [86]: an MCDA method "should be seen as a tool for going deeper into the decision problem, for exploring various possibilities, interpreting them, debating and arguing, rather than a tool able to make the decision. We suppose further that the model of preferences used by the method is, at least partially, co-constructed through interaction between the analyst and the decision maker (or his representative). This co-construction should account for the consequences on which the actions will be judged and for value systems related to the decision context."

A specific preoccupation of Bernard Roy was related to the imprecision, uncertainty, ill determination of the performances assigned by considered criteria to the actions under evaluation (see, e.g., [83]). Again we can find the attention to the "ill-structured, knowledge-rich, nonquantitative decision domains" of the above mentioned article of Herbert Simon.

With respect to the interest to handle ambiguity and uncertainty in the data, Roman Słowiński had the possibility to interact and to cooperate with another great personality, this time, directly related to artificial intelligence: Zdzisław Pawlak, one of the pioneers of Artificial Intelligence and Computer Science with worldwide influence. Zdzisław Pawlak is specifically well known for his rough set theory [74] but he also significantly contributed to many branches of theoretical computer science, mathematics, and logic [79]. In the preface of his seminal book [75], presenting rough set theory he writes: “This book is devoted to some areas of Artificial Intelligence: knowledge, imprecision, vagueness, learning, induction and others” and also “The main issue we are interested in is reasoning from imprecise data, or more specifically, discovering relationship between them.” Again, you can see that Zdzisław Pawlak was sharing with Herbert Simon and Bernard Roy the same interest in the imperfection of data. Roman Słowiński met Zdzisław Pawlak in the middle of eighties of the last century and he was immediately interested as explained by himself [94]: “Personally, I am grateful to Professor Pawlak for revealing me the concept of rough set at the beginning of its conception. Together with my brother Krzysztof, a surgeon, we had the privilege of working with him on the first real-world application of rough set theory—verification of indications for the treatment of duodenal ulcer by HSV.” These joint scientific meetings also initiated next Roman Słowiński’s work on generalizations of the rough set theory to take into account various types of imprecision and on a more general exploitation of rules, resulting from the simplification of decision tables, see, e.g., [64, 95–98]. Recall that Roman Słowiński with his cooperators organized in Kiekrz near Poznań the first international workshop on rough sets theory and was an editor of one first multi-authors monograph on rough sets theory and intelligent decision support systems [93]. Then, he has continued to work on the rough set theory of Zdzisław Pawlak combining it with the MCDA ideas of Bernard Roy, proposing many original contributions and advances relevant both for rough set theory and MCDA, orienting both of them in an AI perspective.

The above considerations show that the genesis of Roman Słowiński’s scientific project of combining Operations Research and Artificial Intelligence in Intelligent Decision Support Systems is the result of the interaction of the great scientific personality of Roman Słowiński with the three great scientific personalities of Jan Węglarz, Bernard Roy and Zdzisław Pawlak. This permitted to realize the vision drafted by Herbert Simon, the founder of intelligent support systems, in his short paper that very probably was unknown to all of them (we were not able to find any citation of that paper also in the scientific productions of Jan Węglarz, Bernard Roy, and Zdzisław Pawlak).

A confirmation that what we have reconstructed corresponds to the scientific project Roman Słowiński has been pursuing can be meaningfully found in the following frame of an interview he recently released [29]:

[...] computer systems were and are created with the intention of decision support. [...] Its development accelerated after World War II with the transition of military operational techniques to civilian operational research, which became a scientific discipline practiced at the border of economics and computer science. In 1950, Alan Turing posed the question

of whether machines could think in the pages of the journal *Mind*, and from 1956 the term “artificial intelligence” began to be used to refer to computer systems that relieve humans of certain intellectual tasks, that is, support their decisions. This is how operations research and artificial intelligence came together to form intelligent decision support systems, which also owe their effectiveness to the high computing power of computers and the Internet, which is a huge database. A feature of AI is learning from observations accumulated in large data sets. As Herbert Simon put it in the 1980s, learning allows adaptive changes to a system that make it perform the same or similar task more efficiently next time. An intelligent decision support system uses AI precisely in the aspect of learning from data about the decision situation, thus making the user more familiar with the situation, as AI discovers regularities, anomalies, cause-effect relationships, that is, it discovers knowledge useful in decision making. [...] The data provided to the system may be incomplete, inaccurate, subject to random fluctuations, and partially contradictory. Different mathematical theories and models, such as probability calculus and statistics, rough set theory, or fuzzy set theory, deal with extracting knowledge from such “imperfect” data.

We want to conclude this section with some other words from another interview of Roman Słowiński [71] clarifying his specific “humanistic” approach to the intelligent decision support system domain:

These systems [intelligent decision support systems] help humans to better understand the decision-making situation and recommend solutions that are consistent with the preferences of a given person or group of people, that is, with their value system. These systems are interactive, because there is a dialogue between the machine, which works according to an algorithm, and the user: we need to let the machine know our preferences, then the machine algorithm will produce a recommendation that is consistent with the model of those preferences, and the human can either accept that recommendation or provide new preference information in response, and such a process loops until a satisfactory recommendation is obtained. Such a decision support process is said to be “human in the loop of the system.”

1.2 Short Biographical Notes

Roman Słowiński was born in Poznań, Poland, on 16 March 1952 into the family of Lech Słowiński, a professor of Polish philology, and Melania née Michalska. He received his MSc degree from the Electric Faculty of the Poznań University of Technology in 1974, followed by his doctorate (PhD) in 1977 under the supervision of Jan Węglarz. In 1981 he obtained the degree of higher doctorate (DSc) (Habilitated doctor in Polish system) from the same University. He attained the national rank of professor in 1989, and since 1991 he has held the position of Full Professor at the Poznań University of Technology. Since 2003 he is also a Professor at the Systems Research Institute of the Polish Academy of Sciences in Warsaw. Between 1995 and 1997 he held the European Chair at the University of Paris Dauphine. He was also an invited professor at the Swiss Federal Institute of Technology in Lausanne, the University of Catania, Polytech’ Mons, University of Michigan-Ann Arbor, Yokohama National University, Université Laval-Québec, University of Missouri-Columbia, University of Osaka, Polytech’ Tours, Ecole Centrale Paris, and many others.

In 1989 Roman Słowiński founded the Laboratory of Intelligent Decision Support Systems (IDSS; <http://idss.cs.put.poznan.pl/site/idss-en.html>) at the Institute of Computing Science, Poznań University of Technology. He has been chairing IDSS continuously until now. Furthermore he created and led a new Master of Science specialization at Poznań University of Technology devoted to Intelligent Decision Support Systems (the first Master program in this domain in Poland).

He became a Corresponding Member of the Polish Academy of Sciences in 2004, and an Ordinary Member in 2013. Since 2013 he has been a member of Academia Europaea. In 2011–2018 he held the post of Chairman of the Poznań Branch of the Polish Academy of Sciences. From 2015 till 2020 he was an elected Chairman of the Committee on Computer Science of the Polish Academy of Sciences. In 2019 he was elected by the General Assembly of the Polish Academy of Sciences to the post of Vice President of the Academy for the 2019–2022 term.

Other positions he has held include:

- Deputy Director of the Institute of Control Engineering, Poznań University of Technology (1984–1987),
- Vice Dean of the Electric Faculty, Poznań University of Technology (1987–1993),
- Professeur en chaire européenne at Université Paris-Dauphine (2003–2009),
- President (2010–2012) and fellow (since 2015) of the International Rough Set Society;
- Vice president of Polish Operational and Systems Research Society—POSRS;
- Member of the scientific council of Polish Artificial Intelligence Society—PSSI;
- Expert panel member of the European Research Council, PE6-Computer Science (2009–2013);
- The Vice-chairman of the Social Advisory Council at the Archbishop of Poznań.

Roman Słowiński has received many acknowledgments and prestige awards. We have already mentioned the prestigious EURO Gold Medal that he was given in 1991. In 1997 he received the Edgeworth-Pareto Award by International Society on Multiple Criteria Decision Making. Poland awarded Roman Słowiński with the Annual Prize of the Foundation for Polish Science, the highest scientific honor in the Country. He was also given the Scientific Award of the President of the Polish Academy of Sciences (2016) and the Scientific Award of the Prime Minister of Poland for creating a scientific school of Intelligent Decision Support Systems (2020). In 2016, he also received the Scientific Award of the President of the Polish Academy of Sciences. Furthermore, he was honored in his hometown, Poznań. The society of the 19th century Polish positivist Hipolit Cegielski gave him the title of “Outstanding Personage of Organic Work” (2017), and the City Council of Poznań awarded him the title of “Distinguished Citizen of the City of Poznań” (2018). In 2021 Roman Słowiński has been promoted “Officier dans l’Ordre des Palmes académiques” by the French Prime Minister to reward his research work in the field of computer science and his unfailing commitment to the development of Franco-Polish relations in the academic and scientific field.

Roman Słowiński is Doctor Honoris Causa of Polytechnic Faculty of Mons (2000), University Paris Dauphine (2001) and Technical University of Crete (2008). He is also a Honorary Professor of the Nanjing University of Aeronautics and Astronautics (2018).

Roman Słowiński is fellow of IEEE (the Institute of Electrical and Electronics Engineers—2017), IRSS (International Rough Set Society—2015), INFORMS (the Institute for Operations Research and the Management Sciences—2019), and IFIP (International Federation for Information Processing—2019). He was also an active member of Polish Information Processing Society (PTI) and Polish Artificial Intelligence Society (PSSI).

Since 1999 Roman Słowiński has been contributing to the development and promotion of Operational Research as Coordinating Editor of the European Journal of Operational Research (Elsevier, CiteScore=8.5), which, also due to his incessant work, is now a premier journal in Operations Research. In years 1998–2003, he was editor of Decision Analysis Section of the International Journal on Fuzzy Sets and Systems. Currently, he is on editorial board of twenty scientific journals.

Since 2007 Roman Słowiński has been a coordinator of the EURO Working Group on Multiple Criteria Decision Aiding, succeeding Bernard Roy, who founded it in 1975. He has also been President of the INFORMS Section on Multiple Criteria Decision Making for the two years period 2020–2021.

1.3 Advice and Supervision of New Researchers

In his academic career, Roman Słowiński has been a mentor and advisor to many young researchers and students. So far, he has promoted 26 doctoral students, many of whom have continued their scientific careers, achieving postdoctoral habilitation degrees (13 in Poland) or professorships. They were successively: Eduardo R. Fernandez (the first of Roman Słowiński's supervised PhD student that defended his thesis in 1987), Marek Kurzawa, Wiktor Treichelt, Mariusz Boryczka, Piotr Zielczyński, Piotr Czyżak, Jerzy Stefanowski, Jacek Żak, Andrzej Jaskiewicz, Maciej Hapke, Piotr Zielniewicz, Krzysztof Krawiec, Robert Susmaga, Paweł Kominek, Maciej Komosiński, Jacek Jelonek, Szymon Wilk, Roman Pindur, Irmina Masłowska, Bartłomiej Prędkie, Izabela Szczęch, Wojciech Kotłowski, Krzysztof Dembczyński, Jerzy Błaszczyński, Miłosz Kadziński, and Marcin Szeląg. Many of them have already raised their own doctoral students, so it can be stated that Roman Słowiński is more than the scientific father of many, many researchers.

Let us emphasize that Roman Słowiński in his cooperation with PhD students and younger colleagues not only plays the role of a mentor but also is even more of an advisor and partner, leaving to his collaborators a large space of research freedom encouraging them to be independent in a perspective of a very open discussion. He also allows them to explore interesting research problems, which are sometime distant from his main interests.

Furthermore Roman Słowiński reviewed many dissertations, both in Poland and abroad, and collaborated with many researchers contributing to the development of their careers. In the Sect. 1.5 we will provide a bibliometric review of his joint publications and discuss his research impact.

Roman Słowiński has also always encouraged and motivated colleagues, especially if young and at the beginning of their scientific carriers. Very often these colleagues started some scientific project with Roman Słowiński and became his friends beyond the scientific activity. For instance Constantin Zopounidis met Roman in Lamsade, the laboratory of Université Paris Dauphine and the CNRS founded by Bernard Roy as a researcher centre in Operational Research and Decision Aiding, in the early 1980s. In that occasion, after a discussion about multicriteria decision aiding and financial modeling, Roman Słowiński asked Constantin Zopounidis to write a paper for the Journal “Foundations of Control Engineering,” a quarterly peer-reviewed international journal published by Poznań University of Technology since 1975—that since 1990 changed name becoming “Foundations of Computing and Decision Sciences.” Constantin Zopounidis wrote an article entitled “A Multicriteria decision making methodology for the evaluation of the risk of failure and an application” [107], which was published in 1987. It was one of the first papers of Constantin Zopounidis that after started a cooperation with Roman Słowiński on the subject of that paper resulting in the publications of several articles in prestigious journals [22, 99, 101].

1.4 The Main Research Contributions of Roman Słowiński

As explained in Sect. 1.1, the scientific carrier of Roman Słowiński started in the area of project scheduling. In that domain he gave relevant contributions related to multiple category resources, multiple job modes, multiple criteria, and uncertainty. More in detail, his contributions were related to Resource Constrained Project Scheduling [8, 73, 106] and scheduling problems with preemptive activities (jobs) to be scheduled on unrelated parallel machines (processors) with additional limited discrete resources [91]. A specific mention deserves the pioneering contributions on fuzzy scheduling [52] and, overall, multiobjective scheduling considering conflicting criteria such as project duration or maximum lateness [92, 100].

In fact, also due to the cooperation with Bernard Roy, MCDA became, in a second moment, the most relevant research area of Roman Słowiński that has given many diversified contribution in different directions:

- interactive multiobjective optimization: in this context we remember a classical interactive multiobjective optimization method [56] in which the decision maker’s preference is modeled through the piecewise linear utility model of UTA method [55], an interactive method in which an outranking relation is used to select solutions to be proposed to the decision maker [58], a visual interactive method, called FLIP, handling multiobjective linear programming

problems with fuzzy coefficients in the objective functions and the constraints [17], interactive procedures based on an achievement scalarizing function based on weights of objectives compatible with preference information supplied by the user [57, 60]; in this domain, a specific mention deserves the contribution in the heuristics for multiobjective optimization: in this perspective let us remember the Pareto simulated annealing for fuzzy multiobjective combinatorial optimization [53], and overall, several methodologies to drive evolutionary multiobjective optimization algorithm towards the most desirable region of the Pareto front using preference information supplied by the decision maker such as NEMO methods [9, 10] based on ordinal and robust ordinal regression and some methods based on contraction of preference cones [61];

- ELECTRE methods: Roman Słowiński has proposed some relevant extensions of the ELECTRE methods introducing two new effects called reinforced preference and counter-veto effect [85] and specific procedures permitting to handle hierarchy of criteria [14, 18]. Roman Słowiński has also introduced the induction of parameters of ELECTRE methods from decision preferences through ordinal regression approach [68]. Roman Słowiński has participated also to the development of very reliable decision support systems for the applications of ELECTRE methods [69]. Let us mention one of the first and most well-known real-world applications of ELECTRE methods [87], related to the use of ELECTRE III [81] for programming a water supply system (WSS) for a rural area. Roman Słowiński has been also working on the axiomatic basis of ELECTRE methods [102]. Let us also remember a very comprehensive and updated state of the art on the ELECTRE methods [28].
- robust ordinal regression: in fact this can be considered a specific MCDA approach originally proposed by Roman Słowiński [44, 47]. Differently from the classical ordinal regression [55] that aimed to represent preferences expressed by the DM with a single specification of a given decision model, very often the additive value function, robust ordinal regression takes into account the whole set of specifications of the considered model that are compatible with the preference information supplied by the DM. Robust ordinal regression, originally proposed taking into account additive value functions used to handle ranking problems [44], was extended and generalized in a vast diversity of directions considering representation of intensity of preferences [27], sorting problems based on additive value functions [46], ELECTRE methods [48], hierarchy of criteria in value functions [13] and ELECTRE methods [14, 15], interaction of criteria in value functions [51] and ELECTRE methods [16], and so on.

Data analysis based on rough set theory is the third pillar of the Roman Słowiński's research activity. We have already mentioned that he did the first real-world medical applications of the rough set theory [78] based on the development, together with his cooperators, of the first software to apply rough set approach [96]. Roman Słowiński proposed also some remarkable extensions such as the rough approximation based on a similarity relation being only reflexive that generalizes the classical indiscernibility relation of original rough set theory which, being an

equivalence relation, is not only simply reflexive but also symmetric and transitive [98]. He studied also rough approximation in case of missing or imprecise data [95], a methodology to apply the decision rules obtained from rough set approach on the basis of their closeness to objects to be classified [97]. Roman Słowiński applied rough set theory also in business and finance [22, 101].

From the beginning of the 1990s Roman Słowiński started to be interested in applying rough set approach to multiple criteria decision aiding [76, 77]. The proposed approach was based on the idea of supporting decisions by means of the “if ..., then ...” rules obtained from preference information supplied by the decision maker in terms of example of decisions. In fact, the information requested, the examples of decisions, as well as the information supplied, the decision rules, were simple and easily understandable for human. However, its restriction was noticed in the application of rough set theory to multiple criteria decision aiding. Rough set theory is based on the indiscernibility relation that holds between two objects if they have the same evaluation with respect to all considered attributes, so that if two objects are indiscernible they should be assigned to the same class. Instead, multiple criteria decision making is based on preference relations that respect a dominance principle for which if one alternative a has an evaluation not worse than another alternative b on all the considered attributes, then a has to be considered at least as good as b . These considerations matured gradually in a certain number of years with a sequence of steps. First, the idea that the object of a rough approximation has to be a preference relation rather than a classification was taken into consideration [30]. The approach gave some interesting results, but in a first moment still the usual indiscernibility was continued to be applied. The necessity to pass from indiscernibility to dominance was in a second moment matured, at the beginning with a specific “single level” dominance used to approximate a preference relation [33]. The clear idea of substituting indiscernibility with dominance and on this basis reformulating the whole rough set theory appeared for the first time in a paper in which rough set approximation was used to the problem of bankruptcy evaluation [31], further developed and extended in [34], and finally published in its definitive form called Dominance-based Rough Set Approach (DRSA) in [37] which is one of the most cited papers both in the domains of rough set theory and multiple criteria decision aiding. In the following years, DRSA has continued to be extended and applied in many domains thanks also to the algorithms [35, 105] and software [6] developed by Roman Słowiński and his cooperators. Among the most relevant extensions of DRSA proposed by the same Roman Słowiński let us remember

- the variable consistency DRSA [3, 36] permitting to discover strong patterns in the data through a relaxation of the dominance principle,
- an extension of DRSA permitting to handle missing values [32],
- an extension of DRSA to handle decisions under uncertainty and time preferences [45],

- an interactive multiobjective optimization method in which the preference information supplied by the decision maker is represented in terms of DRSA “if . . . , then . . .” decision rule [43],
- the stochastic DRSA [63] resulting in a probabilistic model for ordinal classification problems based on a statistical approach relating DRSA with machine learning approach [62].

In addition to the main research areas discussed above, Roman Słowiński with his cooperators contributed to many problems in the field of artificial intelligence, in particular, knowledge discovery from data and machine learning. We will mention just some of them:

- new methods of evaluating rules discovered from data, including studies on values rule evaluation measures [49], in particular, starting from an initial idea presented in the paper co-authored also by Zdzisław Pawlak [39], promoting Bayesian confirmation measures and investigating their formal properties [50],
- new methodologies for interacting with human analysts to evaluate and select the most meaningful decision rules induced with the rough set approach [11], taking also into account paradigms of multiple criteria perspective [103],
- an approach to evaluate the most important sets of elementary conditions in rules by an adaptation of set functions used in cooperative game theory [42],
- online inductions and evaluation of rule classifiers [11, 40],
- selection of the most relevant subsets of features in the data processing steps of knowledge discovery [104, 105] as well as in combination with artificial neural network learning [59],
- new algorithms for discovering rules with handling semantically correlated attributes [19, 38, 40],
- specialized rule-based ensemble classifiers [2, 4, 5, 20, 21],
- nonparametric ordinal classification with monotonic constraints [62],
- procedures to interpret classifiers with an additional dialogue with users [7].

Finally, it is necessary to mention the involvement of Roman Słowiński in many practical applications of the above-discussed methods, in particular, in the field of medicine [26, 66, 67], environmental protection [12, 24, 61], medical [25, 101] and technical diagnostics [72], banking and finance [22, 31, 101], as well as in preferences learning, e.g., in the domain of customer satisfaction [1, 41].

1.5 A Bibliometric Analysis of the Research Activity and Impact of Roman Słowiński

Roman Słowiński is an exceptionally active and creative author of many scientific texts. While writing them, he collaborated with many co-authors, inspired other researchers, and influenced research conducted in many fields, as we discussed in

the earlier sections of this chapter. In order to discuss his creative writing activity, we present below a bibliometric analysis of his publications.

Let us recall that bibliometrics studies the publishing material quantitatively [23]. Here we will focus on an individual author by analyzing such indicators as the number of publications, their total citations, cites of the most visible papers, the h —index [54]. Furthermore we will identify the journals and other publication sources where he published most often together with the fields and the most important topics/keywords of his contributions. This part is somehow inspired by earlier types of such bibliometric analysis undertaken in such studies as, for instance, [65]. We will also determine his most frequent co-authors and comment on his research network and other publishing activities.

This analysis is done using the following bibliography databases and web search engines: Scopus (Elsevier's abstract and citation database), Web of Sciences (currently maintained by Clarivate Analytics), and Google Scholar. It is also supported by considering some summary information provided by DBLP—a computer science bibliography website. The search process was carried out in October 5, 2021.

1.5.1 Numbers of Publications and Citations

Roman Słowiński has published over several hundred texts depending on the bibliography source. These numbers and citations are presented in Table 1.1. Note that Web of Sciences Core Collection is the most restrictive to selected journals and main conferences while Scopus contains the larger collections of the good quality materials. On the other hand Google Scholar indexes other conferences and electronic materials, therefore its database and the number of found publication links are usually clearly bigger.

The numbers of publications in each of these bibliography sources are very high. If one analyzes the annual distributions of their numbers—see figures available in Scopus or Web of Sciences interface—they increased since beginning of the 90' (4–6 per year), to approximately 10–14 between 2000 and 2010, and an even higher numbers more recently. The highest number of 22 publications occurred in 2012 year. These are, in any case, very high indicators proving his extremely rich scientific activity.

Table 1.1 Numbers of Roman Słowiński's publications, their citations and h index

Database system	No. publications	Total no. of citations	No. of citing documents	h -index
Scopus	325	14,727	8036	61
Web of Sciences	275	10,894	6238	51
Google Scholar	> 500	30,378	–	87
Dblp	264	–	–	–

The interesting information on the different types of publications may be found in dblp website. According to it Roman Słowiński co-authored:

- 117 journal papers,
- 114 conferences papers,
- 17 chapters in books and collections,
- 8 being editor or co-editor of multi-author’s monographs.

This is somehow consistent with a similar analysis of the author output panel available in Scopus (called document by source view) where also the numbers of different journals and conferences papers are approximately the same (although with advantage for journals). Following this Scopus report the Springer Lecture Notes in Computer Science including Subseries in Artificial Intelligence is the most numerous outlet for the publication of conference papers and chapters (87 publications—26.9%—for all 325 papers). Nevertheless one should notice a relatively very high number of Roman Słowiński’s publications in many journals. The most frequent journals are analyzed in the next subsection.

The total numbers of citations presented in Table 1.1 are very high and should be regarded as definitely above the average values of even very good researchers. Moreover its dynamics is constantly increasing since the 90s—which is illustrated in Fig. 1.1 as the number of citations received in each year. As one can notice, the number of citations has increased significantly though time since the end of 70s in the previous century. Following Scopus summaries Slowinski’s publications were receiving around several hundreds of citations per year till 2003, then the numbers

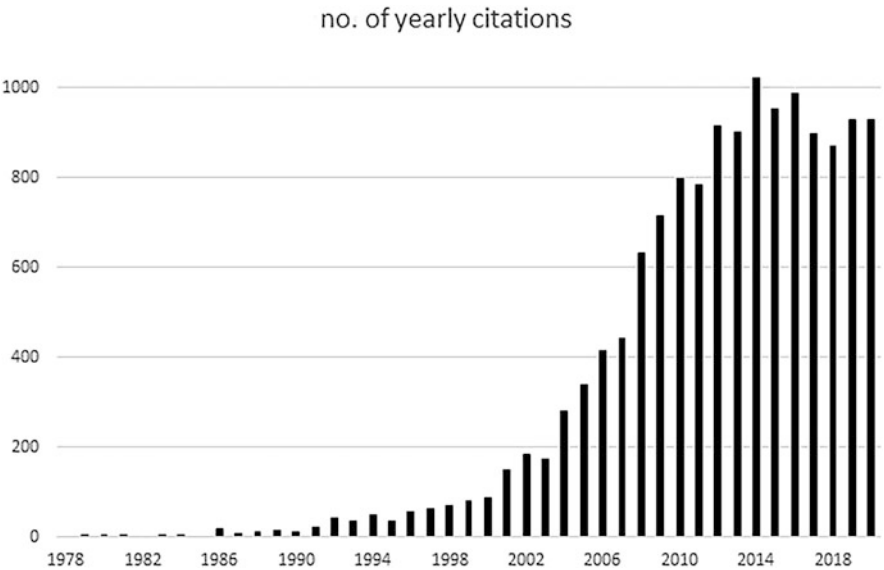


Fig. 1.1 A number of annual citations of papers