



Opinion Makers Section

THE ART AND SCIENCE OF PROBLEM SOLVING

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*Study the science of art
and the art of science.*
- Leonardo da Vinci

1. Introduction

In our educational institutions and in our culture in general, there is a split between art and science. It is believed that these two ways of working and thinking, the artistic attitude and the scientific attitude are two very different worlds, they are like oil and water. Although the link between art and science has historically been very close, exemplified by Leonardo da Vinci, the ideal that Leonardo represents is really not agreed upon by the art and science communities. It is the opinion of the author of this paper that this distinction between and separation of art and science is artificial and increasingly anachronistic. Fortunately things are changing; new fields arise from the synthesis of other fields. For instance, scientists are relying more and more on visual communication, and artists are working increasingly with computers. There is a

common place to transfer information, ideas and knowledge. Visual problems are ultimately the same across disciplines.

The main purpose of this note is to reflect, elaborate and document about how the concept of "the art and science of problem solving" can be used in the real world to deal with important and complex problematic situations in Society. Here, the OR worker is both the artist and scientist supporting a group to deal with a mess. As a scientist, he will be using when needed scientific approaches, experimentation, simulation, mathematical modelling and soft approaches in the problem solving process. As an artist, he will metaphorically speaking be like a painter who combines colours and shapes (the participants in the process) to create an art work (the problem solving process). Or, he is the director of a theatre group performing a piece of art. For the sake of concreteness let us first discuss a real-life case study.

2. Case Study: Planning of High School Examinations in Denmark

This is a real-life and large scale logistic problem where a computer based support system has been developed and implemented. The system has been running at the Danish Ministry of Education since 1992.

2.1 Background

In Denmark, all planning of the official examinations at high school level is centralized at the Danish Ministry of Education. Denmark is the only country where such planning activities are centralised nationally. This cumbersome task had become increasingly difficult and time consuming due to educational reforms in 1998.

The Danish academic school system is divided into primary school (grade 1 through 9/10), high school (grade 10/11 through 12) and university/college, where primary school is the only compulsory school. High school, in the broad sense, has several channels, the academics as opposed to the technical or commercial high schools being the most attended ones. Approximately one half of all primary school graduates continue onto an academic high school.

The academic high school system has two major channels: The Gymnasium which is a 2 or 3 years package, 3 years being the most common, and higher preparatory school (HF), a two years package. Through a system of merits, it is also possible to obtain an equivalent qualification through individual study-plans over several years (VUC). Denmark has 77 Gymnasiums, 25 HF-schools, 77 VUC-schools and 69 schools with both Gymnasium and HF curricula. This amounts to approximately 115,000 students and 12,000 teachers.

The students of the Gymnasium and HF are evaluated at the end of each school year. This evaluation includes oral and written examinations in certain courses. The planning of written examinations is much simpler since the days of examination are given before the start of the school year. This is necessary since all students answer the same examination questions and obviously they must do this at the same time. In what follows *examination* means oral examination. A *sensor* is an eligible and ministerial appointed person - usually a high school teacher from another school - and an *examiner* is the person who conducts the examination - usually the teacher of the course.

An examination is carried out in the following way: A sensor arrives at the school to observe the examination of each student conducted by the examiner for a fixed amount of time. After each student examination, the sensor and the examiner agree on a grade for the student and then continue with the next student on the course, if any.

To encourage students to exhibit "good student behaviour", i.e. not miss classes, deliver term papers on time, etc., a bonus is granted in terms of a reduced number of examinations. Almost 95 percent of all students achieve this bonus. While a final year student could be examined in 7 subjects, "good students" will only have to attend 3 or 4 examinations. The decision of which 3 or 4 subjects the student is to be examined in is drawn in private for each student and is not revealed until the last school day. Consequently, the student must prepare himself for all 7 subjects during the regular school year.

The examinations are gathered in a reserved 5 week period at the end of the school year from mid May to mid June. The Gymnasium only uses the last 3 weeks, except for final year students who also use the second week. First year HF-students use the last 4 weeks and VU-students and final year HF-students use all 5 weeks. Except for national holidays (which

have a maximum of three whole days), the examination are placed Monday-Friday.

Previously, the examination planning was carried out by examination planners at the Ministry of Education using pencil and, especially eraser. Data was reported from each school on paper and sent by snail mail. In 1990, it was decided at the Ministry to develop an information system containing all relevant school data. The basic system is now an Oracle database with applications developed using Oracle tools and C-programming. Different systems are attached to the database, the examination system being the largest and most complex. A communication system handles the input of new data which is submitted from the schools to the ministry on floppy disks.

2.2 The problem and the approach

Summarizing, we can state that the task is to design and implement a computer based decision support system to plan and schedule the annual oral examinations for secondary education in the whole Denmark. For each student, it has to be decided:

- The number of oral examinations
- The subjects to be examined on
- The day, hour and room number for the examination
- The examiner, and
- The sensor.

In practice, there are two main interrelated factors that determine the process of the solution of the above mentioned problem. The *technical approach*, i.e. the suitability of the techniques, methods, software, procedures, and so on, included in the whole decision support system, and the suitability of the *social process* related to the problem solving process itself. In Hansen and Vidal (1995), the technical approach has been described. The second factor demands close interaction and collaboration between the group work, decision makers, experts, consultants and facilitators. In this paper, we will primarily be focusing on the social processes though some aspect of the first factor will be shortly mentioned.

The planning problem described above is a complex and quite difficult combinatorial problem. It contains many decision variables; it has a variety of criteria and many feasible and satisfying solutions. We shall now elaborate on these observations.

Real life planning situations are usually complex. The examination planner has to comply with national laws and customs and must assist schools with their specific problems, making the

examination period as smooth as possible. Obviously, a computer system should support him in this task, rather than introduce additional limitations.

The examination timetabling problem is well known for its mathematical difficulty. This is also true for the assignment problems related to our planning problem. Since a student will normally take more than one examination, a school may have as many as 1500 student examinations. Each student examination is to be scheduled on a specific day, which produces very many decision variables. This assignment problem will contain more than 100 million binary decision variables if formulated as a traditional 0-1 optimization problem.

Having multiple criteria is an ingrained feature of real life problems. These criteria involve a good spread of student examinations so as to provide good premises for each student, minimising the costs for the schools, the counties, and the Ministry, and sharing pedagogical benefits equally among the schools, subjects and geographical areas.

After experimenting with prototypes containing preliminary algorithms, it was concluded that finding feasible solutions did not present major difficulties. Finding satisfying solutions was more difficult but was still consider being attainable within reasonable amount of algorithm construction, system implementation effort and computational time. No demands for achieving optimal solutions were given whereas robustness and consistency were considered to be more important. This is in line with the following heuristic principle: Managerial decisions might be improved more by making them more consistent from one time to another than by approaches seeking optimality to explicit cost models; especially for situations where intangibles must otherwise be estimated or assumed. These observations led to the conclusion that the final planning system should provide the examination planner with suitable information and optimising tools based in heuristic methods, which could be used interactively and that could be stopped at the users command yielding satisfying solutions.

To cope with the complexity of the problem at hand, it was decomposed into four interrelated phases, each dealing with separate tasks and having well-defined goals following well-known heuristic principles (Silver et al, 1980). This decomposition approach follows to a certain extent the traditional approach (pencil and eraser) at the Ministry; this makes easier the final implementation process. This traditional approach was very time consuming for

two planners with a lot of helpers. These four phases are:

- Subject draft
- Examination Chain
- Examination Scheduling
- Assignment of Censorships.

2.3 The work group and the stakeholders

The decision maker was the chief of the Examination Department at the Ministry. He is responsible that all the processes run smoothly. He played no major role in the development of the decision support system. He gave his full support to the work group. The work group was composed of three planners from the Examination Department at the Ministry. Their experiences from many years of work at the Department were extremely useful while testing the different programmes solving each sub-problem. The leader of this group has a central position in the development of the decision support system because as a previous teacher in informatics, he has sufficient background to understand also the technical aspects of the problem and to contribute to its solution. He was at the same the leader, a user and a developer.

Stakeholders were of course the directors and teachers from the different schools that were involved in the discussions about the purpose of the new system, the first tests and the final implementation. The feedbacks from the stakeholders were important during the tuning of the whole system.

The facilitator was my previous student who had developed the technical approach in his MSc thesis; afterwards he was hired as a consultant for the Ministry. He was the facilitator of the whole development and implementation processes. As we will see below other experts were involved. He will seek for the collaboration of the users, the stakeholders, and the experts at the different stages of the development and implementation of the system. Other experts were: One system's designer from a consulting firm and three programmers hired at the Ministry.

2.4 The facilitation process

In this case study the facilitator has two main tasks:

- First, to design, develop and implement a computerized decision support system in close cooperation with the users and other experts. As described above a satisfying system was developed by decomposing the complex problem in a series of interrelated optimization sub-problems each of them

being solved using simple, fast, and reliable heuristic methods. Here the facilitator is working as a scientist using rational approaches, mathematical modelling and algorithms to find satisfying solutions and using the scientific approach to manage the problem solving process.

- Secondly, the facilitation of the work group and the work of the experts in the development and implementation stages of the problem solving process. This was a long process, it started in 1991; the system was used for the first time in 1992, and has been running every year since 1993. The task of the facilitator was to develop an efficient and innovative form of work, a common culture, a positive way of solving conflicts and a creative manner of finding new ideas. Here, the facilitator is working as an artist, he is instructing, directing, and coaching people to be participative, collaborative and creative in the problem solving process. He is like an instructor of a play in a theatre, supporting the different artists to perform their best to create synergetic processes. Or, more metaphorically, he is like a painter where all the participants are his colours to be combined in shapes, shadows and forms to be able to create a master piece.

The technical approaches needed to deal with the above described complex situation are relatively easy to develop. Similar complex logistic problems have been previously solved using mathematical models and heuristics and special dedicated computerized systems.

The real complexity of the problematic situation in question is the social complexity related to the development and implementation of the system by the actors in a participative and collaborative way. It is very complex the management of these social processes. Here the manager, that is the facilitator, is not only a rational and intelligent decision-maker, but also a creative and artistic designer. This managing attitude, managing as designing, is found in architecture, art and design professions.

Of course as with any practical project there have been conflicts, delays, and other problems related to negativity of some of the users or programmers leaving the Ministry; but in the spite of the facilitator's lack of practical experience, he and the leader of the working group believed that it could be done and were highly motivated to do the task.

The system has now been used for 14 years in practice. This has been a great success. For the Ministry, the examination system is the most prestigious system since the examinations have intensive attention from the schools, the public and the politicians; if things go wrong, from the press! Fortunately most people, including many students and teachers, are not aware of the existence of such a decision support system.

3. Art and Science

What is art? The answer to this question is conditioned by the fact that a definition of art has changed due to cultural and historical reasons. The boundaries of art have experienced a radical change over the last century. Previously, art was created in historically validated media and presented in a limited set of contexts for a limited set of objectives, such as search of beauty, religious glorification, or the depiction of persons and places. However, this century has produced new ways of experimentation, breaking and testing of boundaries. Artists have introduced new media, new contexts, new materials and new purposes. This expansion in art activities causes a difficulty in achieving consensus on definitions of art. The following very general definition can be easily accepted:

Making art may be depicted as the process of responding to perceptions, feelings, ideas, dreams, and other experiences by creating innovative works of art through the skilful, thoughtful, and imaginative application of tools and techniques to various media and materials. The "objects" of art that result of encounters between artists and their intentions, their interventions, their concepts and attitudes, their cultural and social realities, and the materials or media in which they choose to work.

Modern artists use unorthodox materials, tools, techniques and ideas inspired by the worlds of science, technology, humanities, economics, psychology, sociology, anthropology, etc. Some are present in non-art contexts, such as factories, laboratories, trade shows, the Internet, schools, and the street. Social interventions are manifold. The process of creating art is filled up of problems related to design and decision-making. The design attitude is related to the creative and innovative process in problem solving, while the decision attitude is related to the scientific approach to problem solving. In this sense, science can support art both providing

materials and the media, and rational approaches to problem solving.

What is Science? Researchers and philosophers on science suggest several defining elements. This set of core ideas, *the scientific approach*, includes the following:

- An essay to understand how and why phenomena occur
- Focus on the real (natural, social, human) world
- Focus on empirical information
- Seeking objectivity
- Use of a rational or logical approach
- Knowledge codify into laws and principles, and
- The continuous testing and refinement of hypotheses.

The crucial assumptions of the scientific approach are that the observed world is essentially orderly, and objectivity can be achieved through self-discipline and the reliance on methods such as the calibration of instruments, repeatability and multi-observed verification. There are of course variations in emphasis. That is, empiricists focus primarily on the role of observations, while rationalists emphasizes on the logical processes of theory construction and derivation. Some enhance induction built from observation; others focus on deduction drawn from theory.

Critical scientists see science as a modern delusion, challenging mainly the possibility of objectivity, noting the decisive influences of gender, social position, culture and history. Critical science is focusing in issues such as the interactions of the observer and the observed phenomena; the role of socially constructed frameworks at all stages; and the social forces and meta-narratives that form the questions and paradigms used in the research process.

Several researchers have contributed to the critique of science. One describes the way dominant paradigms shape the questions that get acceptance and support. Another critiques assumptions of scientific rationality, remarking that nature gives different answers when approached differently. Others analyze the metaphoric language of science, its authoritative voice, and its unacknowledged patriarchal under-life.

In social sciences and the humanities, this kind of critique predominates. Scientists and technological innovators, however, believe in the ability to discover universal truths and assert that

reform can overcome those places where scientific process falls short of its aspirations to universality and objectivity. As validity, it is usually referred to the accomplishments of the rational approach in building robust theoretical structures, and in predicting and controlling the material, organic and social world.

There are some differences and similarities in the practice of Art and Science. In Table 1 the differences are presented while in Table 2 the similarities are enhanced.

Differences:

Art	Science
• Aesthetic, reflective	• Know, understand
• Emotion, intuition	• Reason, logic
• Idiosyncratic, personal	• Normative, principles
• Visual, sonic	• Narrative, textual
• Evocative, subjective	• Explanatory, objective
• Radical change	• Improve, optimise

Table 1. Art vs. Science: Differences

Art vs. Science: similarities

- Observation, experimentation, sensual
- Creativity
- Change, innovation, improvement
- Models, symbols, abstraction
- Universality

Table 2. Art vs. Science: Similarities

4. The Art and Science of Facilitation

The success of the problem solving process is determined by the effectiveness and creativity of the work group. Since the participants are invited or appointed, it is recommended to use some selection criteria. Some of these criteria could be: Representability, goal compatibility, process compatibility, deliberation abilities, positivism, communication abilities, and focus abilities. Obviously, the quality of performance or the piece of art created depends of the raw material you are

using. It is clear that selecting the participants is a very important task, which has to be solved seriously in order to develop effective work group and high quality results. A person, with knowledge and experience with working collaboratively with people, from the organisations involved should undertake this task.

In connection with the work group, there are two social processes to be managed by the facilitator: the problem solving process and the group process. The problem solving process is the way the group act to solve the task supported by the facilitators and some experts. This is the rational and logical process. The group process is related to the manner in which the individuals in the group work together, how they learn, how they communicate, their social and power relationships, and how they deal with conflicts. This is the intuitive and creative process. Obviously, these two processes interact in various degrees. In ideal group work, these two processes support each other. We talk about **group dynamics**, when energy and synergetic effects are created in the group as a result of well-balanced processes where the task is just as important as the group trust and identity.

In addition, there is a third social process: the facilitation process. The facilitators are the managers of the social process and their main mission is to inspire, create, direct, and support group dynamics. By focusing and guiding group members' communication and decision-making processes in a creative and structured form, the facilitators can reduce the chances of engaging in faulty processes and harness the strengths of the group. The facilitator is both an artist, being the director of an artistic performance to be performed by the group, and a scientist, supporting a scientific approach to problem solving. This situation can be achieved using the following guidelines:

- Use approaches, for example creative techniques, and scientific methods;
- Specify a set of objective ground rules for the group work;
- Build on the strengths of the group and protect the group against its weakness;
- Balance members participation;
- Support the group with technological know-how;
- Support the group while dealing with conflicts;
- Plan time to close the different social processes;
- Make the group reflect and evaluate the group dynamics; and

- Empower the group.

The facilitators are constantly thinking (reflection) and listening to the deliberations in the group so they can make suitable interventions (decision making). An intervention means communicating with the group, giving information and knowledge, and encouraging the participants to think about important topics.

Let us elaborate now more theoretically about the essence of the facilitation process as opposed to its existence or its accidental qualities or, in other words, the attributes by means of which facilitation as management can be qualified or identified. As we have seen, facilitation is a purposeful process carried out by one or several persons that goes forward between two interacting processes. First, the logical/rational/legal process carried out by a purposeful group (the problem solving group) that wants to achieve some goals. This process has been called the problem solving process, and is the scene of objectivity. Secondly, the non-logical/irrational/illegal process that refers to the chaotic social process provoked by each single participant, by the participants' relations to each other, or by the participants' relations to the facilitator of the purposeful group, these bring into the participants own subjectivity, intuition, fantasy and feelings. This process can be called the problem destruction process and is the scene of subjectivity.

The facilitation process will move in the grey zone between the scene of objectivity and the scene of subjectivity. The rational and the irrational processes are fighting one another; the one wants to impose over the other. They are in conflict with each other, but they need each other because while the problem solving process seeks to achieve realistic solutions, the irrational process will be the basis for the production of new ideas. Rationality needs chaos, and chaos needs rationality. Due to this contradiction, rationality vs. chaos, we can stipulate that facilitation is a **dialectical** process.

Let us also emphasise that facilitation is a purposeful intervention in a social process, a designed process. Facilitation is not a necessity for the evolution of the problem solving process but it is designed to support the problem solving process. The facilitation evolves very dynamically in a grey zone trying to construct a bridge between the traditional/conservative problem solving (business as usual) and the new/revolutionary power to change. The purpose of facilitation is to seek that the two

above-mentioned processes do not destroy each other, but on the contrary support each other.

The facilitation process can be instructed and directed in different manners, as there are several management styles. The facilitators are the managers of this process. Note that if the group can manage itself, there is no need for a facilitator. That is, the group can learn to facilitate itself. As in any management process, it is a good idea to develop a strategy and design an action plan for the facilitation process. Managing by designing is a fundamental principle in any facilitation process (Boland and Collopy, 2004), therefore all the social processes have to be designed.

Management also involves three other central factors: Power, communication and learning. These aspects are always present in any facilitation process and should be reflected and articulated before, during and after the process. Facilitation becomes **an art** when a synergistic effect is achieved due to the constructive interaction between the rational and the irrational processes. The facilitator then becomes the director of a performance, where each participant plays a central role. By the end of the performance if synergy has been created all the participants will explode in a rush of happiness and pleasure, the pleasure of working creatively and collectively to achieve some goals. It is the same feeling that football players experience after a match where the victory has been the result of a combination of individual creativity, collective hard work and suitable facilitation (the coaching).

Summarising, we can state that the purpose of facilitation as management is not only to solve the task, but other additional goals could be:

- Each participant is a potential facilitator, therefore the importance of the learning dimension;
- Empowerment, the participants learn to be more self-confident and learn to work creatively in a group (creativity is an act of liberation from the jail of our own routines!); and
- Praxis, the facilitators should be able to learn from the experience therefore the importance of the evaluation of the intervention and the systematisation of praxis, in addition learning from failure is a good principle for any facilitator.

5. Conclusions

Everything can be approached scientifically and everything can become art. Our main message is that

in what concerns problem solving in complex situations, it is advisable to use both the scientific and the artistic attitudes. More satisfying results will be achieved, the risk of failures will be minimized, all the participants will be empowered, and everybody will learn from the experience, even the facilitator.

In the case of the planning problem, the Ministry could have ordered the decision support system from a firm instead of in-house development. But in such situation the consequences of failure were too serious and could easily become a political issue. In Denmark, there are too many bad experiences with implemented computerized decision support systems that were extremely expensive to develop and implement and that did not solve the problem, on the contrary caused more problematic situations.

In the case study related to the planning of the examinations the facilitator was educated as an engineer, but in the social process he was managing he was an artist although he was not aware of that. He used his intuition to solve conflicts, supervised the experts and used time to dialogue with the users. He was able to create a common language, a common culture and motivate all participants. He was managing by designing.

This note is based in an extended paper published in Vidal (2005). Further discussions and other applications can be consulted in the e-book Vidal (2006) that can be downloaded free-of-charge.

References

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the Science, IMM, Technical University of Denmark, p. 190, can be downloaded from:

<http://www2.imm.dtu.dk/~vvv/CPPS/>



MCDA Research Groups

Presentation of the research team

« Operations research and multi-objective optimization »

University of Nantes and CNRS, France

Xavier Gandibleux and Matthias Ehrgott

Environment

The LINA (Laboratoire d'Informatique de Nantes Atlantique) is the Computer Science laboratory of the Nantes-Atlantique region of France (FRE CNRS 2729 today, UMR CNRS from January 2008). The lab is hosted by the University of Nantes and the Ecole des Mines de Nantes (School of Engineering) and counts 70 permanent staff. Its scientific project is to develop international research in the "Computer Sciences", with two principal orientations: Distributed software architectures and decision-aid systems. The lab's research teams work on several areas of optimization, such as constraint programming, integer programming, graph theory, bio-informatics, preference modelling and data mining, to name a few.

Formally created in December 2006, the team « Operations research and multi-objective optimization » (ROOM) is the youngest and the smallest of the 11 research teams hosted by the LINA. It is located at the Faculty of Sciences, University of Nantes. With this team, OR and MCDM are now two additional areas of optimization covered by the lab.

The Team

With the recruitment of Xavier Gandibleux in 2004 as full professor in Computer Science by the University of Nantes, and Matthias Ehrgott in 2006

as director of research at the CNRS within LINA, the team is built on basis of more than 10 years of joint work in multi-objective optimization. In 2007, Anthony Przybylski has been recruited by the University of Nantes and he has joined the team as assistant professor. The core of the team consists of these three permanent members.

Non-permanent members are involved in the team for some periods. Sana Belmokhtar (from Ecole des Mines de Saint-Etienne) has joined us as researcher in 2006-2007. She is now assistant professor at the University of Nancy at Epinal. Hadrien Hugot (who is finishing his PhD thesis at LAMSADE, University of Paris Dauphine) got a post-doctoral position in our team funded by the CNRS. He will join us for one year, starting in October 2007.

Master and PhD students contribute to the works of the team. Currently Julien Jorge is preparing his PhD thesis and another PhD student will join us soon. Former PhD students who prepared their thesis under our supervision are Xavier Delorme (now assistant professor, Ecole des Mines de Saint Etienne) and Anthony Przybylski (now assistant professor, University of Nantes).

Research Activities

Our work, based on discrete optimisation in Operations Research, focuses on the accumulation of knowledge towards the development of advanced optimization methods that are capable of solving complex optimization problems in reasonable time. The optimization problems of interest are reference problems in discrete optimization and their application in socio-economic contexts, such as railway transportation (capacity of railway infrastructure), airline operations (crew scheduling), communication networks (routing policies, deployment of new infrastructure), and health (radiotherapy treatment of cancer).

In this context, the motivation characterizing the research direction of the team is to study, model, and solve large scale multiobjective discrete optimization problems. Procedures for these problems are essentially problem dependent and employ, among others, efficient enumerative methods or hybrid optimization techniques (multiobjective metaheuristics and exact algorithms). Our research directions are:

1. **Fundamental:** Study, characterization, and understanding of discrete and combinatorial multiobjective optimization problems.

2. **Methodological and algorithmical:** New techniques and methods for the solution of large scale discrete and combinatorial multiobjective optimization problems; Development of algorithms to improve the efficient solution of NP-hard single and multiobjective problems.
3. **Validation and verification:** Application to real world multiobjective optimization problems with the ultimate goal of being able to solve concrete problems in complex real world environments (production systems, transport, communication, health). Most applications are collaborations with industrial partners such as Alcatel, France Telecom, SNCF, DB, Auckland Hospital, Air New Zealand.

Some Results of Our Work

State of the Art Annotated Bibliographic Survey. For many years we collected and summarized the literature on multi-objective combinatorial optimization (MOCO) problems. In 2000 and in 2002, papers reporting our synthesis have been published. Later we did a similar work about multi-objective metaheuristics (MOMH).

M. Ehrgott, X. Gandibleux (2000). A Survey and annotated bibliography of multiobjective combinatorial optimization. OR Spektrum, 22(4): 425-460.

Path-relinking for multi-objective optimization. Approximation methods for MCDM problems have received a lot of attention in recent years. With two Japanese colleagues we introduced the path-relinking concept for MOMH with success for many MOCO problems.

X. Gandibleux, H. Morita, and N. Katoh (2004). Evolutionary operators based on elite solutions for bi-objective combinatorial optimization. Chapter 23 in *Applications of Multi-Objective Evolutionary Algorithms* (C. Coello Coello and G. Lamont Eds.), pp. 555-579. *Advances in Natural Computation Vol. 1*, World Scientific, Singapore.

Two phase method for MOCO problems. Introduced in the nineties by Ulungu and Teghem, this method has been considered as a generic method for bi-objective optimization problems. One of the major contributions Anthony Przybylski's PhD thesis has

been the generalisation of this method for dealing with problems with more than two objectives.

A. Przybylski (2006) *Méthode en deux phases pour la résolution exacte de problèmes d'optimisation combinatoire comportant plusieurs objectifs : nouveaux développements et application au problème d'affectation linéaire.* PhD thesis, University of Nantes, December 2006 (In French).

Exact and efficient procedures for solving the linear assignment problem with two and three objectives: Considered as a fundamental optimization problem, we proposed algorithms for the exact solution. They have been demonstrated to be the most efficient algorithms considering the literature available.

A. Przybylski, X. Gandibleux and M. Ehrgott (2008). Two-phase algorithms for the bi-objective assignment problem. European Journal of Operational Research 185(2):509-533

Railway infrastructure capacity The question investigated here can be stated as follows: « How many trains can go through a junction or a station? ». With the cooperation of partners we developed methodologies, algorithms and software dealing with this question. The case studies are real situations from the SNCF (France) and the DB (Germany) networks.

J. Rodriguez, X. Delorme, X. Gandibleux, Gr. Marlière, R. Bartusiak, F. Degoutin, and S. Sobieraj (2007). RECIFE: models and tools for analyzing rail capacity. *Recherche Transports Sécurité*, 95:19–36.

Optimization of radiotherapy treatment design: This complex problem concerns the selection of beams, optimization of beam intensity and scheduling of the treatment unit in order to deliver a radiation dose that destroys the tumour while protecting healthy tissue. The team has conducted work on all aspects of this problem.

L. Shao, M. Ehrgott (2007). Approximately solving multiobjective linear programmes in objective space and an application in radiotherapy treatment planning. *Mathematical Methods of Operations Research*. Accepted for publication.

Some Major Events Involving the Team Members

The members of the team have been involved in several international scientific events, four of which are immediately related to the MCDM field.

1. MOMH 2002: Multiple Objective Metaheuristics Workshop, November 4-5, 2002, Paris - France <http://webhost.ua.ac.be/eume/welcome.htm?workshops/momh/fillinaddress.php&1>
2. MOPGP 2006: 7th International Conference on Multi-Objective Programming and Goal Programming, June 12-14, 2006, Loire Valley (Tours), France <http://www.mopgp06.org/>
3. MCDM 2008 : 19th International Conference on Multiple Criteria Decision Making, 7 - 12 January 2008, Auckland, New Zealand <https://secure.orsnz.org.nz/mcdm2008/>
4. EMO 2009: 5th International Conference on Evolutionary Multi-Criterion Optimization. First Semester 2009, Nantes, France <http://www.emo09.org/>

At the national level, the French Working Group dedicated to Multiple-Objective Programming (PM2O) has been co-founded on 1999 by Xavier Gandibleux. He has served as the coordinator of this group for four years.

Visitors and Collaborators

Invited professors who visited us recently for a period of one month were Kathrin Klamroth in 2005 (University of Erlangen-Nuremberg, Germany), Eric Taillard in 2006 (HEIG-VD, Switzerland), and Margaret Wiecek in 2007 (Clemson University, USA).

The team also hosts visiting PhD students: Daniel Salazar Aponte from University Las Palmas de Gran Canaria (6 months from Sept 2005) and Andrea Raith from Auckland University (3 months from August 2007). If you are interested in visiting us, please contact us.

We have a long tradition of working with colleagues in OR and MCDM. Several collaborations are on-going with Karl Doerner and Sophie Parragh (University of Vienna, Austria), Dario Da Silva (University of Nottingham, UK), Naoki Katoh (Kyoto University) and Hiroyuki Morita (Osaka Prefecture University) to name a few.

Since 1999 we are involved in research works related to railway transportation. Joaquin Rodriguez (from INRETS, the French National Research Institute on Transportation and Security) is one of our collaborators on this topic.

To conclude this section, we are collaborating also with colleagues of regional institutions: Fabien Le Huédé (Ecole des Mines de Nantes), Philippe Dépincé (Ecole Centrale de Nantes), Vincent

Barichard (University of Angers) and Marc Sevaux (University of South Brittany-Lorient).

Projects

The team is strongly involved in a large regional project called MILES since the regional council « Pays de la Loire » has recognized « Decision Aid Systems » as a prioritized research theme. In associating the regional research teams in optimization inside this project, it represents a significant task force in the west of France.

Software

RECIFE is a decision support system specifically designed for the analysis of railway infrastructure capacity. For a given station or node of the network, various functionalities such as verifying the feasibility of expected traffic, studying infrastructure saturation and stability of resulting timetables are offered to a decision maker. Two geographical situations have already been studied: The Pierrefitte-Gonesse node located north of Paris and the Lille-Flandres station.

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Forum
(Robustness Analysis)

Robustness analysis in project prioritisation

Alec Morton

London School of Economics and Political Science

Background

A common approach to prioritising investment opportunities (for example, scientific projects) is to sort them in some sort of value for money ordering, that is to say in terms of a ratio v_i/c_i where v_i is a measure of value of a project, and c_i is a measure of the input cost, with i a project index from $K=\{1, \dots, k\}$. In this note, I'll suppose for simplicity that v and c are elicited directly, although they could and often would arise from some transformation and combination of more disaggregate judgements. This priority ordering may be used by the organisation for a one-time allocation of some fixed budget as part of a planning process. Alternatively, it may be kept in a manager's desk drawer, in case a sudden cash or capacity crunch forces the organisation to disinvest from marginal projects: having already thought through priorities can mean that the organisation can respond to this sort of challenge in a relatively co-ordinated way.

Costing and valuation are however, difficult tasks: few assessors can assert their complete confidence in the figures they supply. Accordingly, it is helpful to have a sense of the robustness of this priority ordering. Some people, including this author, find it natural to ascribe a probabilistic meaning to robustness (Butler, Jia et al. 1997; Lahdelma, Hokkanen et al. 1998; Jiménez, Mateos et al. 2005; Morton 2007; Tervonen and Figueira forthcoming). The question which one asks if one takes this view is: if assessments are subject to error, how confident can one be in the priority order delivered by the model?

I shall formalise this notion of error in judgement. To start of with, suppose that we have elicited vectors of cardinal valuations $v=(v_i)$ and of costs $c=(c_i)$ for the projects. Suppose further that there are true costs and valuations (in a sense to be discussed subsequently). As our state of knowledge of these is uncertain, think of these as random vectors and write them as $V=(V_i)$ and $C=(C_i)$ respectively. The expected values of V and C may or may not be equal in value to v and c : in the former case, we will say the assessments are unbiased, in the latter that they are biased.

Given v and c , it should be possible to put the k projects in a value for money order: I will write the rank of an individual project i in this ordering as $o_i(v, c)$, thus defining a vector-valued function $o(v, c)$. Similarly, the (random) vector of project ranks according to their true costs and valuations is $o(V, C)$. With modern software it is easy to find a simulated distribution for $o(V, C)$. One possible way of presenting the information back is just to display box plots (Butler, Jia et al. 1997) of $o_i(V, C)$ for each i . However, in an application setting, the number of projects can be quite large and so there may be an interest in having some sort of summary measure. I propose as a measure of the robustness a function of the form:

$$G(o(v, c), E(g(o_i(v, c)- o_i(V, C))), \dots, E(g(o_k(v, c)- o_k(V, C))))$$

where E is the expectation operator. For convenience, I'll call the terms $E(g(o_i(v, c)- o_i(V, C)))$ the Expected Transformed Rank Differences (ETRDs). Somewhat similar rank-oriented summary statistics have been proposed by Lahdelma and Salminen (2001) but their interest is primarily in identifying attractive compromise solutions in 1-of- n choice tasks rather than in prioritisation tasks and so

their development is somewhat different from that here.

This set-up raises some interesting questions of which I now consider three.

Three questions

1. What distributional forms are appropriate for C ?

If the approach outlined here was to be built into software, I envisage that users could parameterise distributions selected from a menu based on the degree of uncertainty that they feel about v and c . However, the question arises of what should be included in this menu of distributional forms? Answering this question convincingly would require some sort of empirical data gathering exercise. If we were measuring the error properties associated with the measurement of some physical property (mass, volume, etc), what one should do is apply the instrument repeatedly to establish the spread of measurements, and validate against some more accurate instrument to identify whether bias exists. Some authors (e.g. Kleinmuntz 1990) have argued that this sort of reasoning is applicable in the case of modelling error in judgement. However, it is hard to see how one could operationally establish a distribution under this interpretation, as unlike physical instruments, people have memory, with the consequence that successive elicitations can hardly be said to be under the same circumstances.

Accordingly, a more appropriate strategy of investigation may be to identify a number of qualified and reasonably homogeneous cost assessors, and invite them each to assess the costs of the list of projects. The existence or otherwise of systematic bias could be established by investigating the relationship between the assessed judgements and the actual experienced cost of the actual delivered project. The reader will note that the above procedure yields *not* the distribution of true scores given a judgement, but the distribution of judgements given some true score. With suitable supplementary data gathering, however, Bayes Theorem would enable us to deduce the former from the latter.

2. What distributional forms are appropriate for V ?

Establishing an appropriate distributional form for V poses a parallel but more tricky problem to establishing a distributional form for C , since

judgements of value, by their nature, are not "right" or "wrong" in any absolute sense, and so it is hard to think of them as deviating from some underlying true value.

This doesn't give us any difficulty in establishing a distribution of assessments, which is as easy or difficult as in the case of cost assessments discussed above. However, it does make it hard to say how we should establish "true" values. One option (which Kleinmuntz seems to suggest) is to take the mean of the distribution of assessed values as the true value. This has the consequence that value judgements cannot be biased: they must, definitionally, be on average correct.

An alternative view would be to try to develop a parallel approach to that suggested above for dealing with cost. In this case, one would contrast the *ex ante* judgements of value of projects prior to sign-off with *ex post* judgements of value subsequent to delivery. The analogy with cost is not complete, since organisations have to arrive an agreed definition of what things cost for financial reporting purposes, but not of what things are worth. Thus, this approach would pose some tricky methodological challenges, but could – perhaps – be doable.

3. How should we select functions g and G ?

g 's purpose is to transform the rank difference between the ranks according to the elicited values and the ranks according to the true values. The simplest option is to take $g(x)=|x|$. This gives twice the weight to a movement of two places in the ranking to one place. However, one can imagine cases where decision makers might feel either more than or less than twice as bad as a consequence, suggesting g should take be a convex or concave increasing function of $|x|$ respectively. One could also imagine cases (for example, where judgements are systematically biased in some way) where a decision maker may be interested in knowing which options tend to move up and which tend to move down the ranking. In such cases, it might be useful to make g a vector-valued which splits a variable into its positive and negative parts, *i.e.* of the form $g(x)=(\max(x,0), \min(x,0))$.

In some circumstances, it may be that one can simply take G as the identity function, and produce a vector of ETRDs for each project i . This could give quite a bit of insight – for example, if the options have a single peaked distribution of values/ cost, one would expect that those in the centre of the

distribution would have higher ETRDs for comparable levels of error, since those projects would have more options in their immediate neighbourhood.

Let us suppose however that we are interested in producing a single "headline" statistic which synthesises all the ETRDs. One possibility is the average ETRD,

$$\frac{\sum_{i=1}^k E(g(o_i(v,c) - o_i(V,C)))}{k}$$

However, often, when priority orderings are used to support decision making, a triage line of reasoning is relevant: options high in the priority ordering will probably be done, and options low in the priority ordering will probably not be done, and so the really critical ranks are those of the options in the centre of the ordering. In this case, one might be interested in some sort of weighted average ETRD,

$$\frac{\sum_{i=1}^k w(o_i(v,c)) g(o_i(v,c) - o_i(V,C))}{\sum_{i=1}^k w(o_i(v,c))}$$

where $w(o_i(v,c))$ is some sort of concave function which peaks in the middle of the range.

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Consultancy Companies

Company Spotlight: Innovative Decisions, Inc. (IDI)

Innovative Decisions, Inc., (IDI), in Vienna, Virginia, is one of a few firms that considers itself to be a "decision analysis" firm. IDI supports the needs of analysts, managers and senior decision-makers through its consulting, facilitation and training services. While IDI also delivers operations research, statistical, and systems engineering support, "helping people make decisions" is the common theme among these domains and is IDI's core business. Started in 2001 by Terry Bresnick and Dennis Buede, IDI now has twenty-seven people delivering decision analysis services. We are still a virtual company, operating primarily within client spaces. We go in and out of client sites, we operate from home offices, but we really have no base location. The vast majority of IDI's client base is in the public sector of the United States.

IDI focuses on four major business areas:

- Decision Modeling and Analysis: Building models and conducting analyses that support solving a specific problem or making a decision.
- Decision Conferencing: Facilitating project teams and working groups of decision-makers and other experts where solutions are based on group consensus.
- Research in Decision-Making: Focusing on individual and group decision-making

processes, decision-oriented methodologies, human factors, and cognitive biases.

- **Decision Analysis Training and Seminars:** Providing tailored instruction and coaching on decision analysis topics pertinent to specific clients.

The nature of the consultancy practice at IDI is somewhat unique. Most of us are decision analysts by trade. Many of the people in the company came out of Ron Howard's program at Stanford in what used to be the Engineering- Economic Systems department. We also have several people with a business school background. More recently, we have added several folks with operations research backgrounds, with several coming from the Naval Postgraduate School and from the Information Technology program at George Mason University. Additionally, we have several social scientists who emphasize the cognitive side of decision making. When we bring the four aspects together, the engineering component, the business component, the operations research component, and the cognitive psychology component, it makes for a fairly powerful combination of perspectives to bring into an organization.

We can best describe our decision analysis practice in terms of the following questions:

What our clients are really buying? Are they buying our analysis where we represent some subset of expertise, or are they buying a process where the goal is to help their experts and their analysts have a process that they can use that they can repeat and they can solve the important problems of the day. For the most part, we sell processes – decision analysis processes that produce valued results in terms of insights into their decisions based upon inputs from key people in a cost-efficient time frame.

Are we selling subject matter expertise or just good advice? Very often people come to us because they trust us. We're objective, we don't have a stake in the decision and they're looking for someone to guide them along the correct path. They're not necessarily looking for sophisticated analytic models; they're not impressed by the fact that we can do large optimizations; they don't come to us because we can build huge probabilistic models. What they really need

is good advice on how to look at their problem, how to structure their problem, how to solve their problem.

Are we providing consulting services or technology transfer? Sometimes, we help a client with a one-time application. The client has a specific problem and we help them solve it and we leave. Other times there is a series of problems that might feed into or build onto another. Frequently, what they really want is to learn how to do decision analysis themselves – the client is looking for technology transfer.

The most unique aspect of our practice is the decision conference. To use the words of Ron Howard to describe decision analysis in general, a decision conference is a structured conversation. Decision conferences were started by Decisions and Designs, Incorporated (DDI) in the late 1970s. They were developed by Dr. Cameron Peterson. The notion is to bring together the experts from the field and the experts on the process – the decision analysis experts. The field people provide the subject-matter expertise. The decision analysts are in the roles of decision process facilitators – often as a team of three. There is the lead facilitator who takes the group of the experts from the company or organization, walks them through the process and builds the models in real time; there is the person who would implement the decision models using computer-based decision tools; and there is the recorder who documents the rationale for the quantitative and qualitative judgments and writes the conference report as it proceeds. All three of the roles are filled by decision analysts and are interchangeable. At any time, any of the decision analysts can assume any of the roles. Collectively, IDI personnel have facilitated more than 2500 decision conferences and working sessions.

We use a wide range of analytical methods and tools. The analysis techniques that are finding the broadest application today include Bayesian networks and dynamic decision networks, decision trees and influence diagrams, multi-attribute utility analysis, benefit/cost analysis, social networks, and step-wise simulation. Specific tools that are used frequently include Logical Decisions, Hiview, Equity, @Risk, Netica, DPL, DATA, Analytical, Crystal Ball, Extend, ORA, and I-Think, among others. Most of the tools we use have been chosen with the human factors side of decision analysis and

decision making in mind. The interfaces are designed for easy use. The use of color has meaning. Scrolling is minimized to maintain focus – concepts that are designed from the cognitive side of group decision making. For decision conferences, we want tools that help the group converge quickly after we've been through the divergent phase in the decision making process. When software doesn't exist that meets the client needs, IDI creates it.

As we look to the future at IDI, we envision modest, steady growth in our highly specialized decision analysis niche. The key to growth to date has been forming strategic alliances with the well known, large consulting firms. By complementing their subject matter experts with our unique perspectives and skills in decision analysis, we can provide a powerful "one-stop shopping" team that can meet most clients needs. The most substantial challenge that we face is finding a continuous stream of skilled decision analysts. As we grow, our reliance on a strong mentoring program for junior analysts will become critical.

Please visit our website at www.innovativedecisions.com for more information.

Terry Bresnick, President, IDI

Software

CSMAA: A user-friendly software for SMAA-III/TRI/3

Tommi Tervonen
(tommi.tervonen@it.utu.fi)

Stochastic Multicriteria Acceptability Analysis (SMAA) is a family of decision support methods that allow to handle problems with partial or missing information about parameter values. Even though the different methods of the family have been used in real-life problems, a user-friendly software has never been available for wider audience. In order to allow the methodology to be used by analysts and academics less accustomed to the techniques of

numerical computation, we have developed a software implementing some methods of the family. The methods of the software apply Monte Carlo simulation to calculate descriptive indices that characterize the decision making problem.

The software was done in conjunction to developing SMAA-TRI and SMAA-III, the two newest methods of the family. It implements these two as well as the SMAA-3 method. In future, other SMAA methods will be added to software. SMAA-TRI is for sorting problems, that is, for assigning alternatives into ordered categories. SMAA-III is for ranking the alternatives. SMAA-3 is similar to SMAA-III, but instead of the complete ELECTRE III procedure, it uses a less discriminative less-in-favor exploitation rule. Another approach to using the software is to use SMAA-TRI and SMAA-III as ELECTRE TRI and ELECTRE III with imprecise parameter values and missing preference information. In this case the SMAA-type indices can be used for parameter sensitivity analysis of the two ELECTRE methods.

The software allows imprecise criteria measurements to be defined with discrete or real values. With discrete values, each number in the imprecise range is considered equiprobable, while with real values they can be defined with uniform or Gaussian distribution. In the case of SMAA-III and SMAA-3, ordinal measurements are allowed as well. In this case, the alternatives are ranked with respect to the ordinal criterion. If SMAA-TRI is used, also the profile measurements as in ELECTRE TRI can be defined with imprecise values. The thresholds of ELECTRE model can be defined with absolute (+-) of percentage values. Both of these can be imprecise within some interval. The uncertainties of criteria and profile measurements can be automatically set to 5%, 10%, or 20% of the values. This way the methods can be used for automatic robustness analysis. Therefore users accustomed to use ELECTRE III or ELECTRE TRI can apply the software to obtain robust conclusions with their model of exact values.

Various preference information can be incorporated into the model. Exact preferences (weights), lower and/or upper bounds for weights, or ordinal (ranking of the weights) information can be used. All other weight information except upper bounds for weights do not cause high computational burden. Upper bounds instead can slow down the computation, but usually this slowdown is of low factor and does not need to be taken into account.

Announcement:

The "Useful links" section of the group's homepage

(<http://www.inescc.pt/~ewgmcda>)

is being enlarged. Contributions of URL links to societies, research groups and other links of interest are welcome.

A membership directory of the European Working Group on "Multiple Criteria Decision Aiding" is available at the same site. If you would like to be listed in this directory please send us your data (see examples already in the directory).

Contact: José Figueira (figueira@ist.utl.pt) and Luís Dias (ldias@inescc.pt)

**Web site for the EURO
Working Group "Multicriteria
Aid for Decisions"**

A World Wide Web site for the EURO Working Group on "Multicriteria Aid for Decisions" is already available at the URL:

<http://www.inescc.pt/~ewgmcda>

This WWW site is aimed not just at making available the most relevant information contained in the Newsletter sections, but it also intends to become an online discussion forum, where other information and opinion articles could appear in order to create a more lively atmosphere within the group.

**Groupe de Travail Européen "Aide Multicritère à la Décision" /
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Call for Papers

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3- Operations and Supply Chain Management (3.1- Operations and Supply Chain Optimization; 3.2- Environmental Issues and Sustainable Operations; 3.3- Close Loop Supply Chains).

4- Cross-functional Emerging Domains (4.1- Actor Networks and Collaborative Models; 3.2- Organizational Learning and Knowledge Management; 3.3- Education in Engineering Management).

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Papers, in final form, should be Word documents written in English, have a maximum of five pages and use the format prescribed in [TRANS-JOUR.doc](#). Each paper should mention the name and number of Topic and Sub-Topic within which it is submitted. Papers will be blind reviewed.

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