

Practical Decision Aid for Complex Decision Processes: why Strategic Analysis with STAN is not a black box.

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ABSTRACT

The main difficulty in urban planning decision processes is that several aspects must be taken into account simultaneously, together with their consequences. The human mind alone is not able to manage and process all the information correctly or completely. Quantitative models are able to formalize problems and define evaluation functions, providing unbiased analyses focused on the important aspects of the decision. Operations Research models are able to solve complex systems of relations, with the additional possibility of optimizing an objective function. These models have

demonstrated to be very useful in urban planning, where decisions must also pass through the delicate process of negotiation, which typically involves several decision makers with conflicting viewpoints. Using for example Mathematical Programming makes it possible a fast evaluation of the different decisions, as well as, of the relations, interactions, and consequences of the alternative decision choices. Sharing this kind of information helps the decision makers to cooperate and find a final common decision. Also transparency and traceability of the decision process are intrinsically guaranteed by the adoption of the formal method. In this paper we discuss this point starting from the origins of the 'Strategic Analysis' approach. Then we illustrate the model and the method which are implemented in STAN, a software recently developed to provide a useful operational tool for decision aid in urban planning processes.

DECISION PROCESSES AND OPERATIONS RESEARCH

Taking decisions is a difficult task in every application field. This is a main issue for industries and companies, but also in the service sector, in Economics and Finance, in Medicine, etc. Nowadays, the use of mathematical tools in complex decision problems is a common practice, typically for the solution of technical problems, but also in many other situations in which the decision process can be supported by information deriving from processed data and related computations. The best known and common tools for quantitative analysis generally come from Statistics, Mathematics and Algebra, whose task is to measure data, explain relations, and produce information that may help in the decision. Operational Research (or Operations Research – OR) has brought a new way of applying mathematics, planning and formalizing complex systems of relations, and introducing the revolutionary idea of solving optimization problems.

OR dates back at the time of the Second World War, when the approaching of the conflict required new strategies and operational tools to exploit technologies at best for military purposes. Soon after the end of the war, OR fast became a widespread discipline; starting from the 1950's, it was also recognized in the academies all over the world, including Italy in the middle 1960's. In the reconstruction period after the war there was a natural tendency to apply these innovative techniques in different areas, since in many countries all the economic and industrial sectors required restarting their activities and encouraging a new and fast development. In the recent years, the OR approach has deeply diffused also in every management context where people are called to take strategic decisions that influence the future of their activity. Basing on quantitative analysis, Management Science is the discipline which develops methods and models to organize and support complex decision processes (Winston and Albright, 2001).

OPERATIONS RESEARCH AND THE STRATEGIC CHOICE APPROACH IN URBAN PLANNING

In 1963 the Institute for Operational Research (IOR) was founded by a group of researchers of the British Operational Research Society. They were interested in the application of OR to Human Sciences and their studies were particularly focused on the application of OR to decision problems arising in the public sector. Urban planning was one of the involved areas, and one of their projects was related to the study of planning processes by local administrations (municipalities). The innovative approach was soon appreciated in some localities, especially those where the war had provoked hard damages which needed a major intervention in urban organization and reconstruction. The case of the city of Coventry was the object of a complex study developed in a strict relation between the researchers from IOR and the Coventry Council, with a detailed analysis of all the available information, and an active participation of the involved actors to all the (formal and informal) steps of the decision processes (Friend and Jessop, 1969).

The main result of the study was the proposal of the ‘Strategic Analysis’ approach. According to it, the decision process is seen as a strategic activity, able to act in a context where uncertainty is an unavoidable element to face with. It determines a context that may change in the decision process, due to unexpected situations that arise during the negotiation. Stakeholders should take decisions by adapting to this changing scenarios, being able to maintain a continuous exchange between governments and community’s representatives. Some techniques, like AIDA (Analysis of Interconnected Decision Areas), were developed to structure the problems so that alternative possible decisions could be clearly defined and evaluated by each decision maker on the basis of the same information. In the following years, the Strategic Analysis approach was widely discussed in the urban planning literature,

especially in Great Britain, also giving rise to many applications and experiments (Faludi, 1987; Friend, 2001; Yewlett, 2001).

Following this approach, in the middle of the 1970's, Stan Openshaw and Paddy Whitehead, from the University of Newcastle Upon Tyne, proposed a new method to solve decision problems in the AIDA framework. They introduced formal mathematical formulations of the decision problem, based on optimization techniques from Integer Linear Programming. They also developed a software called DOT (Decision Optimization Technique) which was able to find an 'optimal' solution of the formulated models, even if the development of computer technologies at that time was not sufficient to guarantee an efficient solution process (Openshaw and Whitehead, 1975, 1977, 1978).

This kind of approach was hardly criticized, even by the researchers from IOR, since, in the opinion of the many, Operational Research – or, better, Optimization – was used in a too hard way. The method was not acknowledged in the right way, and it was accused of making an extreme use of computers and to rely too much on solutions produced by automatic procedures that may be optimal for a formal model but do not necessarily correspond to the best solution for the planning problem.

Actually, this was not in the authors' intent; rather their aim was to exploit the powerful tools of Mathematical Programming for providing concrete aid in the decision process. Quantitative analysis makes it possible a fast evaluation of the different decisions, as well as, of the relations, interactions, and consequences of the possible alternative choices. In this context, OR is used to conduct the process in a clever way, so that each decision maker develops his/her evaluation on the basis of the same shared information. Moreover, intermediate evaluations or decisions may themselves produce new

(updated) information to be used in the following steps of the decision process. In this way the negotiation becomes a traceable process with at least two main benefits: on the one hand, each stakeholder can develop his/her final decision looking at the whole course of his/her positions during the negotiation (and – why not? – also at those of the other actors, since multiple decision makers must not be necessarily always in conflict, and it may happen that comments and observations of one of them influence the point of view of another, even in a positive way!); on the other hand, the main steps of the negotiation process can be recorded to be available to the public administration in a future similar context. For example, it can be recorded why a decision was taken/not taken annotating a set of quantitative evaluations and/or tracing the consecutive contrasting positions of the different stakeholders that finally produced a shared decision.

OR DECISION AID IN URBAN PLANNING DECISION PROCESSES

The original and powerful contribution of OR in urban planning decision processes is its ability to formalize problems and define evaluation functions. In any complex decision problem the main difficulty is that several aspects must be taken into account simultaneously, and their combinations could be so many that the human mind is not able to organize all the information and use it efficiently.

In general, a decision problem can be classified as ‘complex’ when there are many variables that interact in the decision, and when they are interconnected by a series of relations and implications that must be taken into account simultaneously when processing the decision. The problem becomes even more complicated when there are several decision makers that have to cooperate and find a final shared decision. In urban planning there are all the above ingredients, and

the problem is even harder since decisions must pass through the delicate process of debate and negotiation among a set of decision makers (stakeholders) who typically have conflicting viewpoints. The same happens also in decision contexts in the Public Sector, where, differently from the Private Sector, decisions must be taken in order to meet the goal of public benefit (at least ‘in principle’).

Combinatorial Optimization is a branch of OR which studies efficient techniques to solve complex combinatorial problems. Several smart and powerful tools are available, but they are mathematically sophisticated, so that, typically, people coming from Social and Human Sciences are afraid of using it, or do not trust in the efficacy of their application.

Our opinion is that mathematical decision aid could be a useful and practical support for public decisions in urban planning, able to provide concrete help in combining the different views of the many actors participating to the decision process. Here the meaning of the words must be carefully understood. On the one hand, ‘mathematical’ refers simply to the idea of measuring information and computing quantities that generally helps in understanding the many different aspects of the problem (for example, computing costs or measurable benefits connected to a decision). On the other hand, the (key-) word ‘decision aid’ means that the quantitative approach can only help the decision makers, and it is never meant to replace them. It must be clear that the automatic procedure that mathematics and optimization can provide do not ‘solve the problem’, they just help in evaluating objectively (i.e., on the basis of measurable indicators) the alternative possible choices that, in fact, may be a huge number. Therefore, this must be seen as a tool that supports the decision process through transparent and traceable steps. In this way, additional and precious information can be provided for a given decision process, which is then traced and recorded in order to be conserved and re-used (both

data and processes) also for other similar decisions which may arise in a future occasion and/or in another locality. In public decision processes this is not a rare case, since it frequently happens that the same decision must be taken in the same context at some time lag distance, or in two different geographical areas.

THE STRATEGIC CHOICE ANALYSIS WITH THE SOFTWARE STAN

It is in the above view that the Strategic Choice approach and the AIDA technique were recently reconsidered in the realization of a new software called STAN (from St-rategic An-alysis, but also in honour of the previous work by Stan Openshaw).

STAN is a successful realization of the quantitative analysis approach described above. It is an easy-to-use software, characterized by a simple and user-friendly interface, that applies well assessed and consolidated mathematical tools and optimization techniques (Nemhauser and Wolsey, 1988) to problems that arise frequently in urban planning decision processes. These are conceptually simple problems that can be described to everyone in an intuitive way. In spite of this, they are not simple to solve at all. They need to be formalized by rigorous mathematical and logical models (without affecting the original meaning of the problem) in order to use the powerful solution tools provided by Mathematical Programming.

STAN allows many evaluations under different viewpoints; the implemented mathematical models can be used to analyse economic or environmental aspects, as well as to establish the preferences of a single decision maker. The final aim is to obtain useful information to depict a complete picture of the situation under which the final decision must be taken. The positions of the various stakeholders are never merged together by the software, but they are analysed in an

organized and systematic way in order to make them clear and useful for the negotiation and the interaction between decision makers.

Obviously, a decision maker/user without any specific mathematical skill could be afraid of using this software, but it must not be seen as a black-box. Even if the algorithms implemented in STAN cannot be understood by every user, its output can be easily checked by everyone. In other words, the user does not know how a solution is produced, but he/she is able to verify on his/her own the quality of such solution by simple computations and to compare it to a different alternative (his/her preferred one).

STAN can be seen as a Decision Support System (DSS) for urban planning decision processes, designed to help planners to answer difficult questions without having to worry about technical issues. The users might never even see the mathematical models or the solution procedure, but they have to know which kind of analysis they are performing in order to be able to understand the output. The users have to intervene only to select the input of the problem they want to solve, using buttons, dialogue boxes, toolbars and menus, specifically designed to make these operations easy. Then they see a back end of the software which produces the output of the elaborations. This phase is designed so that the report provided by the software is sufficiently clear to be read and understood by all users.

THE MODEL AND METHODOLOGY IMPLEMENTED IN STAN

Following the AIDA approach, the problem consists of the choice of a coherent set of decisions related to different decision areas. Four basic elements are given; i) a set of decision areas; ii) for each decision area, a set of options, i.e., the possible alternative choices available for that area; iii) a set of criteria for the evaluation of the

options of each area; iv) the set of relations existing between options of the decision areas. These relations specify whether two options can be realized together or not (are compatible or not), thus providing a complete picture of the decision system. The idea is to set a tool able to support the delicate process of evaluation of specific sets of choices, their characteristics and possible consequences. The difficulty of the problem is that exactly one option for each decision area must be selected and the selection of options should be feasible, that means that selected options should be compatible. The combinatorial nature of the problem is then evident, since problem solutions are combinations of options, and the complexity of its solution can be easily understood if one realizes that, even in the simple case in which only 2 options are available for each area, when the problem has n decision areas, the number of alternative solutions exponentially grows with n , and it is equal to 2^n . This means that, if, for example, one has to take a decision with $n=3$ areas, the potential number of decisions is $2^3 = 8$, but this number grows fast, when n increases only a bit. For example, for $n=20$, which is quite a reasonable number of areas in a real-life application, $2^{20} = 1048576!$ This is certainly a number of choices that the human mind cannot easily analyse and compare, especially when, like in urban planning, the number of evaluation criteria for the decision is greater than one, as well as, the number of decision makers.

In STAN the above decision problem is formulated by Integer Linear Programming (Nemhauser and Wolsey, 1988) with binary 0/1 variables. The set of linear constraints included in the program represent the structural relations characterizing the interconnected areas decision framework. They basically model incompatibilities between options from different decision areas imposing that if two options are incompatible, then at most one can be chosen. In practice this means that the possible decisions are either choosing only one of

the two, or no one. In addition, since exactly one option must be chosen for each area, the model includes the ‘natural’ incompatibility conditions holding among any two alternative options of the same decision area (Ricca, 2008).

Let n be the number of decision areas and p_1, p_2, \dots, p_n the corresponding number of options. For each possible option j of decision area i , we introduce a decision variable x_{ij} which takes value 1 when option j is selected for decision area i , and 0 otherwise. Then each variable corresponds to a single decision modelled as an elementary yes-or-no choice (in numbers one-or-zero choice). Then, a complete decision configures as a set of 1/0 values (a vector), one for each elementary decision, and solutions returned by STAN can be easily read and interpreted as a sequence of accept/reject answers to each elementary choice.

The main task in the model is played by the set of constraints which, as a whole, is able to guarantee that output decisions correspond a set of compatible elementary decisions.

First of all, a constraint must guarantee that exactly one option is selected for each decision area. For this, the model includes the following set of n linear equalities by which necessity and mutual exclusion conditions are imposed on options of the same area:

$$\sum_{j=1}^{p_i} x_{ij} = 1 \quad i = 1, 2, \dots, n$$

The other important aspect is avoiding incompatibilities between options from different areas. This is settled via linear inequalities. For each pair of options, say option j of area i and option k of area h the condition is that at most one between x_{ij} and x_{hk} can be selected (set to 1). In formulas, the condition is the following:

$$x_{ij} + x_{hk} \leq 1.$$

Notice that the above constraint is satisfied when only one of the two options is chosen (i.e., $x_{ij} = 0$ and $x_{hk} = 1$ or $x_{ij} = 1$ and $x_{hk} = 0$), but also when no of the two is selected ($x_{ij} = x_{hk} = 0$). This means that the incompatibility between option j of area i and option k of area h is avoided by the model, but the choice is not forced to select one of these two options. In fact, the possibility of choosing different options both for areas i and h is left open.

The above set of constraints describes mathematically what is called the feasibility problem, i.e., the problem of selecting a decision corresponding to a combination of compatible options.

The possibility of introducing an objective function in the mathematical model must be seen as an opportunity and not as a threat. Through an objective we can ask the model to return the best decision among the feasible ones, for example in terms of monetary costs, or we can ask for the one that is the most preferred by one of the decision makers (according to an appropriate and previously fixed score function). One can exploit the model to evaluate any conceivable aspect, provided that it can be formulated as a linear function of the model variables, and to output the decision which ranks first w.r.t. it. This could appear to the non-expert in mathematics a forced way to decide. On the contrary, it is an advantage if the output solution is not taken as ‘the optimal solution’ but just as a good one that, in any case, could, and should, be further investigated and evaluated under other additional important aspects. The advantage of the mathematical approach implemented in STAN is that it is flexible in terms of the possible analysis that it is able to perform. A common mistake that can be made is considering as rigid a tool that is formally correct. This is not necessarily true. One possible analysis with STAN is asking the software to order the

feasible decisions, from the best to the worst, according to one selected criterion. One can order w.r.t. a cost function and then apply again the selection by restricting the set of possible decisions only to those that ranked, for example, within the first cheapest 20. Another possibility is repeatedly solving the same feasibility problem by computing each time the objective function on the basis of the preference system of a different decision maker.

By the mathematical formulation of the combinatorial decision problem STAN can even go beyond the basic feasibility model described above and perform further analyses. The model can be enriched with additional constraints, such as those known as ‘logical constraints’ that are able to formulate via simple inequalities important logical implications that typically characterize contexts with a high degree of interconnection between elementary decisions.

One possible additional request could be imposing that, in case one chooses option *j* of area *i*, it is recommended to choose also option *k* for area *h*. This implication may be motivated by reasons that cannot be formalized mathematically, but, in any case, the model allows to take them into account by just adding one single logical constraint in the model, and without modifying the nature of the model and its readability. Other examples explaining how much STAN is flexible and adaptable to the needs of the decision makers can be found in (Ricca, 2008).

There are additional analyses that STAN is able to perform and that could be very useful for the evaluations during the negotiation process. In the following we list some examples of those that may be exploited by decision makers to interact with the system and use the software to answer to specific questions:

1. The possibility of analyzing decisions by fixing minimum required thresholds (for example when an environmental

- compatibility index must be evaluated) or maximum tolerance levels (for cost-based indices).
2. The capability of automatically excluding combinations of options that cannot be implemented together for structural reasons (infeasible solutions for the mathematical model), thus avoiding further and useless evaluations on them.
 3. The possibility of fixing a variable x_{ij} (option j of area i) at a given value (0 or 1) and filter decisions that are compatible with the already fixed choice. This is an important kind of analysis which may be used when some priorities exist for the elementary decision in a given area.

Several other interesting analyses can be performed with STAN, and several others may be implemented in a future development of the software. The above listed ones are different ways of performing what-if analyses aimed at improving the knowledge of the problem and better specifying the structure of the problem itself. It must be underlined that these tools are available to all actors in the decision process, and, therefore, they can be used to improve the collective knowledge of the problem, since a query by one may produce useful information for all.

FURTHER COMMENTS AND CONCLUSIONS

At the current time, the software STAN is only partially developed. It was mainly used in academic courses and experimented in some test applications for urban planning in small localities (Scattoni, 2002, 2007). In spite of this, in the real-life case studies the use of STAN was deeply appreciated, since, by directly experimenting it, the involved decision makers acknowledged the usefulness of the evaluations provided by STAN for the success of the negotiation.

STAN can also rely on the technological improvements of the hardware of the computing processors and on the continuous

production of new optimization algorithms and solvers. It is susceptible of fast development also thanks to its open source nature that may help in sharing the software, improving its capabilities, and promoting its use. But the step forward to make STAN becoming a ‘professional’ tool is to apply it: to understand how it works, and to appreciate how much it may help the decision process, one must try it.

Under a technical viewpoint, it must be pointed out that the combinatorial problems formulated in STAN (and DOT) are computationally hard in theory. However, this is not a problem in practice, since the integer linear programs used to formalize the problems arising in urban planning decisions can be efficiently solved by the current available optimization solvers, provided that the problem size is not extremely large. This is, in fact, the typical size of problems arising in STAN in which, in spite of the many alternative choices that must be evaluated under many different aspects, the problem can be always formulated as a computationally tractable mathematical model.

It is important to underline that the use of mathematical models and methods does not affect or modify the nature of the problem and the mechanisms of the process. On the contrary, transparency and traceability, which are the essential requisites for a fair and efficient decision process, are intrinsically guaranteed by the adoption of a formal method. This approach is consistent with the philosophy and practice of the strategic choice, fitting the idea that computational tools with an easy-to-read output can actually help the decision process and provide useful operational support. This was, in fact, the original motivation of Stan Openshaw and its research group when they suggested the mathematical analysis framework operating in the DOT environment.

With STAN this framework is further improved. Particular attention is paid to obtaining a system that, at the same time, is technically powerful and easy to use, thus providing a practical tool for supporting the decision process. The only risk is that users may be afraid of adopting it, fearing that they could not understand all steps, or, that someone else could decide in place of them. But the strength of STAN is that it operates independently from the interests of single stakeholders, its aim being exactly the opposite, that is, to produce unbiased information available for all decision makers; if correctly used, it can be a really useful operational tool, helping both the single decision maker and the whole negotiation process to reach a final decision.

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