The Use of Multicriteria Decision Methods in Planning and Design

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ABSTRACT

Fields associated with design and physical planning are appropriate domains for the use of multicriteria decision methods. Various methods are compared and "weighted summation" technique is put forward as the most suitable method for the needs of design and planning. The case of city planning is used to illustrate the methodology. The phases of "design of alternatives", "determination of objectives and criteria" and "evaluation" are described with the help of examples. The paper concludes with principles and problems in the use of multicriteria decision methods in design and planning.

Keywords: City Planning, Decision in Design, Multi-criteria Decision, Weighted Summation Method, Alternatives in Planning

1. INTRODUCTION

Physical planning and design cover a large spectrum of professional fields operating in a great variety of scales, extending from the design of a door handle to the planning of a country, all aiming to remodel the environment: industrial design, interior design, architecture, urban design, city planning, regional planning, etc. The common characteristic of these fields is their location in a grey area between art and science: art demanding creativity -thus arbitrariness and subjectivity- and science requiring rationality -thus objectivity.

A quick examination of the structure of design and planning will show that the decision process is calling for the use of rational methods for the following reasons:

a/ *Multiplicity of interest groups:* transformations and improvements that arise as the consequence of design decisions influence various groups in different ways. Diverging objectives and perceptions of these groups make the decision problem in design a complex process.

b/ *Sequential pattern of decisions:* the designers and particularly the planners are expected to make decisions at different scales during various steps of the design process. In architecture, for example, this chain of decisions may start from the location and dimension of the building to be designed, may contain issues such as relationship with the environment, orientation, number of floors, circulation scheme, interrelation between functions, size of each space, principles in heating and cooling system and may be terminated with such detailed subjects as selection of materials, color, design of specific furniture, etc. An error that can take place in any phase may influence subsequent phases and may lead the design to get weaker and sometimes to unfortunate consequences.

c/ *Complexity of decisions:* each step of the design is a cluster of decisions –often of contradictory nature. The designer is responsible for generating the best set of decisions for the relevant phase. The only way of evaluating weather the proposed design is made out of the best set of decisions is to compare it with other possible designs.

All these facts indicate that -besides problems such as immeasurable factors and uncertainity about future- design or planning process induces the obligation of making decisions usually of irrevocable nature. Therefore, associated fields are appropriate domains for the use of advanced decision techniques. Despite the necessity to work with alternatives and to use objective methods for attaining sound decisions, it is very rare to encounter design professionals applying such techniques in practical life.

2. COMPARISON OF MULTICRITERIA DECISION METHODS IN TERMS OF THEIR RELEVANCY FOR DESIGN AND PLANNING

It is obvious that the complexity of problems -particularly the existence of diverging objectives and immeasurable factors- in design or planning makes multicriteria decision techniques more suitable than uni-dimensional methods such as cost-benefit analysis. But the main question arises during the selection of a specific multicriteria technique to be used in design among the huge set of available methods.

A Classification of Multicriteria Decision Methods

For this purpose, it is necessary to classify and analyse relevant methods. There is an extensive work achieved on this issue by different researchers during the recent decades. In this paper, the classification by Janssen [1] is used for analysing multicriteria decision techniques. Janssen's classification is based on the elements of the evaluation system: the set of alternatives, the measurement scale of the attributes, the decision rule and the valuation function:

- *The set of alternatives: discrete versus continuous problems.* Discrete decision problems contain a finite set of alternatives, whereas the number of feasible alternatives is infinite in continuous decision problems.
- *The measurement scale of the attributes: quantitative versus qualitative attribute scales.* Although the majority of the techniques are designed to process quantitative data, there exist methods to handle qualitative or mixed information.
- *The decision rule: priorities, trade-offs or prices.* Traditional evaluation methods usually involve maximization of a single attribute (money, utility, etc.), whereas in multicriteria analysis priorities reflect the trade-offs of decision makers among objectives.
- *The valuation function: standardization versus valuation.* The measurement of attributes achieved in different units can be transformed either into a common unit by using standardization techniques or into utility indices by defining specific utility functions for each effect.

Validity of the Methods for the Problems of Design and Planning

Each method has its own field of utilization. Therefore, it is necessary to assess available techniques in respect of their relevance to the structure of the problem and to the purpose. A brief analysis comparing multicriteria decision techniques in reference to the structure of design problems is given below:

Each step of the design process usually involves the problem of choice among a finite number of alternatives. But even in reverse conditions, it is always possible to transform continuous problems into discrete problems by taking into account a limited number of alternatives selected in specific intervals. Thus, in most of the cases, methods -such as linear programming- aimed to solve continuous problems are not adequate for design or planning.

In a multicriteria analysis, it is certainly desirable to compare alternatives with exclusively quantitative attribute scale. But, in most of the design problems, it is very common to encounter attributes of intangible nature. Consequently, qualitative or rather mixed methods may be recommended for design or planning. However, one should keep in mind that this kind of methods do not always end with a complete ranking of alternatives. In most of the cases, there is also the opportunity of converting qualitative scales into quantitative ones using scoring, etc. and work with fully quantitative methods.

The multitude of interest groups and the variety of attributes in design and planning requires the use of multi-criteria analysis –where priorities reflect the trade-offs of decision makers among objectives- rather than maximization of a single attribute such as money or utility.

Finally, among the two alternative methods for valuation function, standardization should be prefered to value or utility function because of its simplicity and practicality.

This brief analysis demonstrates that discrete quantitative methods are more suitable to the nature of problems encountered in design and planning. The most frequently used multicriteria method among the available ones is the *weighted summation* technique. This is also the preference of the author of this paper who had the opportunity of applying multi-criteria analysis methods in his professional life since 1980's, particularly in transportation planning and urban design. He has also lead city planning studio courses based on the use of multi-criteria decision techniques at university and compiled his experiences in a book titled “Designing Alternatives and Multicriteria Evaluation in City Planning” [2].

3. WEIGHTED SUMMATION METHOD: A BRIEF DESCRIPTION

For making a multicriteria assessment using weighted summation technique, it is necessary to have more than one attribute or criterion with predetermined relative importances and a set of alternatives. The purpose of the method is to help the decision maker to detect the most appropriate alternative responding to his/her objectives.

The heart of the evaluation process, as it is applied by the author, consists of three successive steps summarized on three tables [2]:

a/ The performances of alternatives a (a=1,…..I) according to criteria c (c=1,…..J) are first gathered in a table called *result of measurements matrix*. Elements s_{ji} of this matrix represent the effect of each alternative “a” for a criterion “c”, measured in the specific unit of the relevant attribute.

b/ Another table called *standardization table* is needed for converting measurements achieved in different units into a common scale (s'_{ji}). This is done through an operation scaling the scores (s_{ji}) according to their relative intervals between the origin (usually absolute zero) and the maximum score:

$$S'_{ji} = \frac{S_{ji}}{\max_i |S_{ji}|} \quad (1)$$

c/ Ultimately, standardized scores are multiplied by the pre-assigned weights (w_j) of each criterion and summed for each alternative in the *final evaluation table*. The alternative with minimum total value is denoted as the best alternative, since design and planning problems usually comprise criteria to be minimized:

$$\underset{a\,=\,1,\ldots,I}{\textit{minimize}} \quad \sum_{j=1}^{J} (w_j s'_{ji}) \tag{2}$$

4. THE CASE OF CITY PLANNING

Multicriteria decision methods can be used almost in all the fields associated with design and physical planning. But this paper will focus on the application of weighted summation technique in decision problems of *city planning.*

Like most of the physical planning disciplines, city planning process consists of a chain of sequential decisions. This process may start at higher scales with decisions on national or regional levels and may extend towards detailed levels such as dimensions of a building in a specific parcel. Decisions that are outputs of higher levels are generally inputs to subsequent phases (Figure 1).

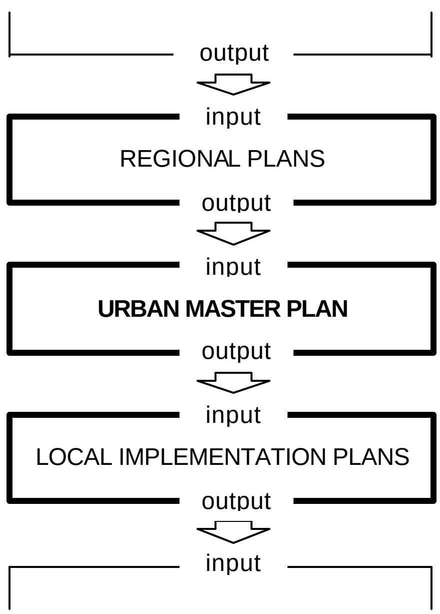

Figure 1. Input-Output Relationship between City Planning Scales

Each of these phases is a potential area for applying multi-criteria decision methods. Among these steps, *urban master plan,* where the decision on the macroform of the city and the location of the main functions are settled, is the most critical one. Decisions at that scale may cause negative effects of irrevocable nature from physical, economic, social and environmental aspects. For this reason, the decision problems related to the generation of urban master plan will be explored as an example to the use of multicriteria methods in planning.

The process of achieving urban master plan supported by weighted summation method is made up of three basic modules: design of alternatives, determination of objectives and criteria, and evaluation. It is, of course, only a step in the sequential decision system of planning, receiving inputs from upper levels and supplying outputs to lower scale planning activities (Figure 2).

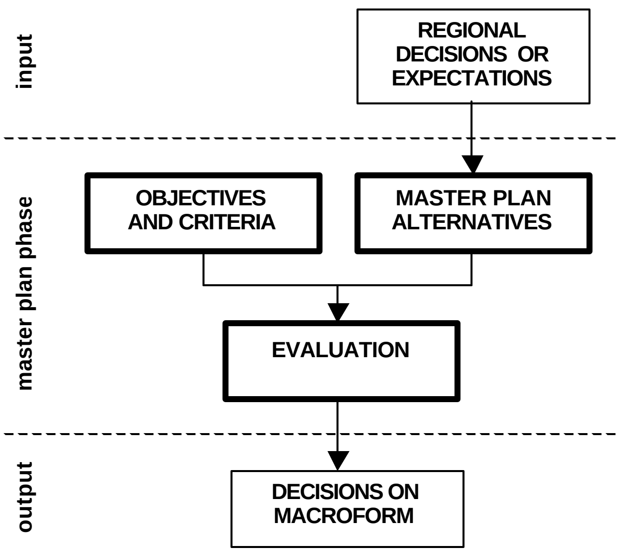

Figure 2. The Role of Multi-Criteria Evaluation in Urban Master Plan Phase

Design of Alternatives

Each one of the master plan alternatives is a candidate for being selected as a definitive plan at the end of the evaluation procedure. Thus, alternatives should be realizable. Creating distinct alternatives with inner consistency is a prerequisite for a sound decision. Inner consistency can only be achieved by perceiving *urban mechanism*: the force that governs the location of activities and the relationship among urban functions. It is of paramount importance to know which and how urban elements effect the location of other elements. The work of Lowry [3] and Echnique [4] on urban models produced a framework for describing the correlation among independent variables as basic employment and transportation, and dependent variables as population, service employment, etc. Such a knowledge will guarantee the generation of realizable scenarios by effective use of planning tools in space and time. One of the basic principles in the creation of alternatives is therefore *viability*.

Another essential principle is *difference* among alternatives. The general rule is to include all realizable alternatives into the assessment process. But, in city planning the number of such alternatives is often too many to handle practically. Therefore, to include alternatives covering a very large spectrum but distictly different from each other will help to reduce the number of alternatives minimizing at the same time the risk of excluding extreme solutions.

As stated earlier, urban master plan is only an intermediate phase in the general process of physical planning. Parameters such as population, function and employment profile of the city are usually the result of decisions taken on a superior level (regional plan). The problem at this stage is limited to the spatial arrangement of these parameters. Consequently, another principle in the design of alternatives is *conformity with higher level decisions*.

Objectives, criteria, weights, measurements

Objectives and criteria: Alternatives are then evaluated against a set of attributes. The author of this paper prefers the hierarchical system cited by McCrimmon [5] where objectives and criteria express distinct notions. This is similar to recent approach of Pomerol and Barba-Romero [6] in which a distinction is made between attributes and criteria.

For the purpose of this study, *objective* is defined as the desired state of an attribute to be reached at the end of the planning acivity. It determines the preference of the decision maker about the related attribute of the city. Objectives are usually abstract statements unsuitable for quantitative assessment.

In this hierarchical approach, *criteria* are used to overcome this difficulty. Criterion is a concrete statement that serves to indicate the level of attainment to an objective. For the sake of comprehensiveness, there may more than one criterion for an objective.

A four-step methodology is proposed by Godard [7] for the determination of objectives: 1/ Research about probable outcomes of alternatives, attitudes and expectations of the press and NGO's, former statements of decision makers and objectives cited in similar studies; 2/ Predetermination phase containing a long and unscreened list of objectives; 3/ Discussion with decision makers for transparency and for easy adoption of the results at later stages; 4/ Final determination covering a list of objectives of optimum length balancing the need for comprehensiveness and practicality.

One may speak of three principles in the determination of objectives:

First, there should not be *any interdependence between selected objectives*. For example, although two objectives such as "minimization of the distance from home to work" and "minimization of transportation operating co
as different statements at a first glance, they will probably be compared using same or similar parameter (total duration of regular daily trips). That will create double counting or over-emphasis on a specific attribute.

Objectives should not imply decisions. Statements containing clearly expressed or hidden decisions would cause early elimination of alternatives against this decision. Therefore, statements like "the city should grow towards the west direction" should be omitted in order to take into account all alternatives. Decisions are expected to settle at the end of evaluation process.

A final principle is the *conformity of objectives to the related phase*. Even though some objectives are correct and valid, they are general goals of planning or society (maximization of the welfare of citizens) or objective of a higher decision level (rapid population growth of the city) and have no practical impact on the evaluation of urban master plan alternatives. Selected objectives should help the assessment procedure in this context.

Weights: Since chosen objectives are not always equally important for decision makers, it is customary to assign weights to objectives. Weights may differ from one case to another depending on the decision maker, city and time. In fact, weights are the mere translation of policies into quantifiable terms. In a healthy democratic mechanism, the decision maker is usually the elected mayor or the relevant body of the municipality.

There are alternative ways of determining the weights of the objectives. Some researchers suggest requesting two by two comparison of objectives from decision makers. This method often leads to inconsistant results during summation process. Another approach is to ask from decision makers a ranking of objectives in respect with their importance. This method solves the problem of inconsistency, but the question of intervals between weights still remains. For example, the weights of four ranked objectives may be 0.35, 0.30, 0.25, 0.10 or 0.70, 0.15, 0.10, 0.05. Janssen [1] cites three techniques for the resolution of that problem: expected value, extreme value and random value. However, after the first ranking of decision makers, it is always possible to prepare alternative weight lists with a brief sensitivity analysis about their probable consequences to evaluation and then obtain the ultimate preference of decision makers.

Measurement techniques: The accuracy in the determination of attainment to objectives is strictly dependent on measurement techniques. Measurement of certain attributes is highly simple. For example, the operation to be achieved for the criterion "minimization of agricultural land used in urban development" is nothing more than measuring agricultural land utilized for development (ha) in each alternative. For more complex attributes, it is necessary to formulate more comprehensive measurement methods. The following example illustrates a more complicated situation.

Let's suppose that the objective of "minimization of environmental damage" is measured by two criteria with 60% and 40% respective weights:

1. minimization of population affected by industrial pollution
2. minimization of population affected by through traffic noise

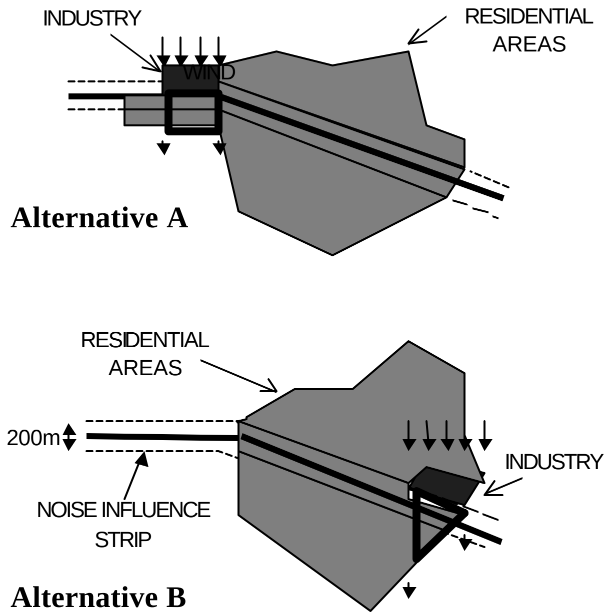

Figure 3. Measurement Method for "Minimization of Environmental Damage" Objective

Industry which is considered as the most important source of air pollution is situated at the west in alternative A and at the south east in alternative B, the north wind being the dominant wind (Figure 3). Residential districts influenced from pollution are areas remaining under the shade of industrial zone shown within broad frames. Population affected by pollution (P) in each alternative can be calculated by multiplying the surface of such areas (A_i) in "hectare" by proposed densities (d_i) in "person/hectare" for these areas.

$$P = \sum_{i=1}^{n} A_i . d_i \qquad (3)$$

For the calculation of the population influenced by the noise of through traffic (N), first the length of the section of the road crossing the city surrounded by residential areas (l_j) in meters is multiplied by 200meters (estimated as the depth of influence) in order to get the surface of nuisance zone (square meter). Then, these surfaces are converted into hectares (10^{-4}) and multiplied by the proposed densities (d_j) in "person/hectare" for these areas.

$$N = \sum_{i=1}^{m} 200.10^{-4} . l_j . d_j \qquad (4)$$

Finally, environmental damage -expressed as the sum of effected persons- can be calculated taken into account respective weights of two criteria.

$$E = 0.6\,P + 0.4N \qquad (5)$$

Evaluation phase

Evaluation process consists of three successive steps: consolidation of measurements, standardization and final evaluation. This methodology described in Section 3 would be better explained by the help of an example. Let us suppose that four urban master plan alternatives (A, B, C and D) are compared against a set of five objectives:

- *Minimization of the loss of agricultural land;* expressed by the criterion of "minimization of 1st grade land used for development", measured in hectares (weight = 0.15).
- *Minimization of infrastructure costs;* including the development of local streets, drainage, drinking water, electricity and telephone (weight = 0.15). Assuming that the cost of construction is the function of the type and the slope of terrain, two criteria are utilized to explain this objective: minimization of the development proposed on "lands with firm geologic formations" and "lands with more than 20% slope" in hectares (respective weights = 0.10 and 0.05).
- *Minimization of transportation operating costs;* assuming that there is a high correlation between cost and duration of travel, this objective is represented by the criterion of "minimization of total daily commuting travel time" measured in minutes (weight = 0.25).
- *Minimization of environmental damage;* (weight = 0.25) expressed by two criteria as explained in the previous example: minimization of population affected by "industrial pollution" and "through traffic noise" measured in number of persons (respective weights = 0.15 and 0.10).
- *Minimization of requirement for new investment;* realization of certain alternatives depends on specific planning tools such as constructing a bridge or a new freeway, transfering certain services to new sites. Therefore, the criterion for this objective would be "minimization of additional investment costs" measured in relevant currency (weight = 0.20).

Consolidation of measurements: Objectives, criteria, measurement units and the result of measurements for each alternative are shown on Table 1.

Table 1. Consolidation of Measurements

OBJECTIVES	CRITERIA	UNIT	Alt. A	Alt. B	Alt. C	Alt. D
Agricultural land	1.grade land	ha.	27	**12**	107	69
Infra-structure costs	Land type	ha.	**0**	28	94	13
	Land slope	ha.	16	**0**	19	42
Transportation operating costs	Travel time	1000 min.	**174**	242	196	235
Damage to environment	Air pollution	persons	5600	**0**	13200	3700
	Noise	persons	**4300**	6500	7300	6800
New investments	Additional cost	10^6 $	102	**53**	81	61

Standardization: Then, measurements achieved in different units are converted into a common scale (%) according to their relative intervals between zero and the maximum score (Table 2).

Table 2. Standardization

OBJECTIVES	CRITERIA	ALT A	ALT B	ALT C	ALT D
Agricultural land	1.grade land	25	**11**	100	64
Infrastructure costs	Land type	**0**	30	100	14
	Land slope	38	**0**	45	100
Transportation operating costs	Travel time	**72**	100	81	97
Damage to environment	Air pollution	42	**0**	100	93
	Noise	**59**	89	100	93
New investments	Additional cost	100	**52**	79	60

Final evaluation: Standardized scores are multiplied by the weight of each criterion and summed for each alternative (Table 3). Since all the objectives consist of criteria to be minimized, the alternative with minimum total value is regarded as the best alternative.

Table 3. Final Evaluation

OBJECTIVES	CRITERIA	WEIGHT	ALT A	ALT B	ALT C	ALT D
Agricultural land	1.grade land	0.15	3.75	1.65	15.00	9.60
Infrastructure costs	Land type	0.10	0.00	3.00	10.00	1.40
	Land slope	0.05	0.57	0.00	2.25	5.00
Transportation operating costs	Travel time	0.25	18.0	25.00	20.25	24.25
Damage to environment	Air pollution	0.15	6.30	0.00	15.00	4.2
	Noise	0.10	5.90	8.90	10.00	9.30
New investments	Additional cost	0.20	20.00	10.40	15.80	12.00
TOTAL			54.52	**48.95**	88.30	65.75

The assessment shows that "B" is the best alternative according to the set of predetermined objectives, criteria, weights and measurement techniques, followed closely by "A".

5. CONCLUSION

The example of city planning described in the above section demonstrates that design or physical planning problems are appropriate domains for the use of multicriteria decision methods. However, the analyst should be cautious during the application of these methods: any inaccurate or inappropriate utilization would lead to the distortion of evaluation system, thus to wrong results.

Assumptions realized during various phases of the process make the system a fragile one. One should ask frequently questions as: "Are all realizable alternatives included in the evaluation system?", "Do selected objectives and their weights correspond to the policy of the decision maker?", "Are the objectives represented comprehensively by selected criteria?", "Are the adopted measurement techniques and units relevant ones?, etc. Particularly in cases as the above example where the dominance of the best alternative is not very distinct, it is advisable to carry out sensitivity analysis for every step of the process and to make corrections by feed-backs when necessary.

Finally, one should keep in mind that the method used is nothing more than an assistance to decision making; it can not replace the decision itself. This fact highlights the importance of the reciprocal roles of the analyst and the decision maker in the process. Mutual respects to the rights of the decision maker and to the knowledge of the analyst are prerequisites for a healthy and sustainable decision.

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