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# AN INTERACTIVE PROCEDURE FOR INDUSTRIAL BUILDING DESIGN CHOICE

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## INTRODUCTION

One of the most widespread multiple criteria decision problems is the problem of the choice of the best version of a complex engineering project design. Different groups of specialists participate in the choice, and directly and indirectly (as experts) they affect the process. In addition, there is a project manager, in fact the final decision maker, who bears full responsibility for the implications of the choice made.

The choice of an engineering project design generally requires complex computer calculations; hence, the development of a rational method for selecting the best version of a complex engineering project design is confined, from a methodological point of view, to development of a man-machine decision procedure exercised by several decision makers, wherein one of them is more influential than the others. Definition of such a problem statement is generally preceded by thorough situation analysis which can be realized, for example, through soft systems analysis [1].

This paper focuses on a specific problem of this type: the problem of choice of an industrial building design. Along with solution of the practical problem the authors formulate a general approach to the class of problems concerned with collective and individual choice under multiple quality criteria.

### Industrial building design

An industrial building is designed by numerous specialists falling into three major groups: architects, industrial engineers, economists, and a project manager who is aware of customers' and inspection bodies' requirements.

All design contributors have their own ideas about the project, set their own requirements and handle specific subtasks. The project manager, held accountable for the final decision, coordinates the activities in each subtask, which is far from easy as the demands to be taken into account are often conflicting. Thus, the design of industrial buildings can be viewed as a multidisciplinary activity, and the outcome thereof as a synthesis of heterogeneous requirements.

The search for an optimal balance of all requirements is exercised at the very beginning of building design, involving definition of its major parameters: length, width, outline configuration, number of storeys, design and layout patterns. Since the choice of the parameters to a considerable degree determines the efficiency of investments in construction and functioning of future production, and the range of values they can take is rather large, it becomes desirable to investigate numerous alternatives to define them.

When current practice resorts to examination of alternative design of industrial enterprises, however, usually not more than two or three alternative designs are developed. The choice of an alternative for further detailed development is most often intuitive; underlying it are past experience of the participating designers, their subjective judgements, traditions.

There are several reasons for this, such as: considerably increased labour expenditure on alternative designs; extended lead time; lack of either a generally-accepted system of criteria of design evaluation or a procedure for choice of the best alternative.

The great national economic significance of the problem considered stipulates the need for design techniques based on a multicriteria approach to problem

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solution, application of modern tools for design analysis and evaluation, and computer-aided design. The suggested method for the choice of industrial building design includes *development* of a *variety* of alternative *choices*.

The approach to each of these elements is to a considerable degree determined by specific features of the problem faced. Design of an industrial building can be treated as an ill-structured problem with a large quantity of qualitative uncertain elements. Their solution is based mostly on experience and knowledge of specialists in this field which implies the necessity of developing rational techniques for their solution.

### Generation of design alternatives

The computer-aided design of versions of industrial buildings involves the following steps. First, consideration is given to the project situation (Fig. 1). The analysis is jointly performed by project manager, chief industrial engineer and architect. This group defines the basic input data — building area, possible number of storeys, layout configuration, construction patterns, constraints affecting the choice of building parameters.

The above data are entered in the program FORGS 2 used in development and

| Design stages | Computer program | Contributors |
|---|---|---|
| 1. Project situation analysis | | Architect, industrial engineer |
| 2. Preparation of input data | | Architect, ind. eng., economist |
| 3. Version development: number of storeys, dimensions | FORGS version | Arch., ind.eng. |
| 4. Version analysis | | Arch., ind.eng. |
| 5. Preparation of input data | | Arch., ind.eng., plumbing eng.,power eng. |
| 6. Development of layout versions | SHEMA package | Arch., ind.eng. |
| 7. Version evaluation | | All principal specialists |
| 8. Version choice | ZAPROS | Arch., ind.eng. |
| 9. Coordination | | |
| 10. Detailing | | |
| 11. Spatial layout | | All specialists |
| 12. Evaluation of spatial layout | UNION REKOR version | Estimator, economist |

FIGURE 1: A project for choice of an industrial building

evaluation of building dimension alternatives having a rectangular front view and the same number of storeys in all parts. Capital investment and costs are calculated for the alternatives which are then printed out for analysis together with the project data such as number of storeys, outline dimensions, distance between major load-carrying structures, operating area, floor area, area of roof, walls, volume of building.

The analysis is carried out by the project manager assisted by the specialists of all groups contributing to the project design: architects, industrial engineers, economists.

The purpose of analysis of alternative designs at this stage is to establish their feasibility in principle. Following the analysis some alternatives can be dropped from further examination and a decision can be taken to alter the input data and constraints. In this case the program FORGS is run again with new data and the obtained set of alternatives is subject to the same kind of analysis. The process is repeated until the obtained set of alternatives meets the requirements of all decision makers: industrial engineer, accountant, economist. Since the industrial buildings are designed rectangular in the plan then the CAD set comprises the major part of all practically feasible design alternatives with regard to the available constraints. In case the specialists deem it necessary to consider an alternative design with a complex plan form (T or M-shaped, etc.) or with a different number of storeys in different parts of the building, they can design a version or a set of versions by conventional methods. The versions-related data are entered in a special program VART and the project designs are evaluated by the same collection of technical-and-economic indices as the computer-aided alternatives obtained with FORGS. The variety of possible alternatives expanded with 'manually' developed ones is passed to the second phase.

The purpose of this phase is to ascertain the practical feasibility of placing a technological process in the buildings with parameters defined at the preceding phase. Accordingly, with the help of program package SHEMA they develop a layout scheme for each alternative that has passed the first 'screening'. This is the most labour-consuming part of alternatives design, and its execution for scores of alternatives by traditional methods is, practically, not feasible.

The computer-based alternatives are analysed with regard to the possibility of siting a technological process within the specified dimensions. The analysis is carried out mostly by industrial engineers with the project manager participating. In the course of analysis, designers can introduce changes in computer-generated solutions and suggest their own ones to be assessed on program package SHEMA by formalised criteria: e.g. total length of transport and engineering service lines, human flows (with regard to intensity), partitions.

## Multiple criteria design evaluation

The running of the above programs results in a variety of design alternatives differing in indicators such as set of columns, length and width of the building, number of storeys, etc. All these factors are considered by the architect and industrial engineer in evaluating different designs from the point of view, respectively, of architectural engineering and convenience of functioning. As for the economist, he is guided by the methods permitting him to obtain a scalar estimate of expenditures required for the accomplishment of each specific design.

In the course of a joint study with an architect and an industrial engineer we managed to define the following criteria for industrial building design evaluation. In analysing a design the architect considers the following variables:

1. Interlocking
2. Zoning of production, auxiliary and warehousing areas
5. Beam span
6. Type of ceiling

7. Environment relation
8. Appearance
9. Dimension treatment
10. Set of columns
11. Vertical service lines
12. Engineering support room
13. Partitions
14. Expansion

The industrial engineer's criteria are:

1. Linearity
2. Continuity
3. Gravity flow
4. Length of service lines
5. Length of flow
6. Intersection
7. Illumination.

For the most part all the criteria are qualitative. In line with the methodological approach developed elsewhere [3, 4, 5] ordinal verbal estimate scales were formulated for each criterion. The wordings of criterion scale estimates contained terms and notions used by specialists. This permitted maximum approximation to the natural language of situation description employed in design organisations. It should be mentioned that the number of grades on criterion scales was around 2-4 which corresponded to substantial changes in quality for each criterion.

It was the discussion with specialists participating in the choice of an industrial building design which allowed us to identify a set of the most significant criteria by which the quality of any project could and should be evaluated.

**Procedure for the best design definition**

The distinguishing features of the considered problem of choice are as follows. There are numerous alternative designs (up to several hundred). Each design is evaluated by multiple criteria (over 20), mostly qualitative. The criterion scales are ordinal with 2-4 quality grades in the form of detailed wordings. Proceeding from the design estimates by these criteria it is necessary to choose the best one.

The specific characteristic of the decision group is that there are three groups of people (industrial engineers, architects, economists) whose interests are each represented by a set of criteria, and a decision maker — the project manager — making a final choice of the design and bearing full responsibility for the choice.

It is well known that there are several requirements for the final solution of a choice problem: classification of the entire variety of alternatives, partial or complete ranking thereof, identification of the best alternative. The latter problem is one of the most difficult from a methodological point of view. Therefore, it is usually tackled in several steps. At intermediate steps the original variety of alternatives is reduced to a subset of the best ones. Then, on the basis of additional information, the best alternative is chosen.

The analysis of a variety of criteria associated with each of the three groups allowed us to identify *hierarchical systems of criteria.* Separate clusters of primary criteria of industrial project estimates reflected different aspects which made it possible to introduce intermediate criteria of project estimates with their own scales. The wordings of intermediate criteria and their scales employed the terms used by specialists of design organizations. Figure 2 shows hierarchical systems of criteria related to the technology and architectural engineering aspects of industrial building designs.

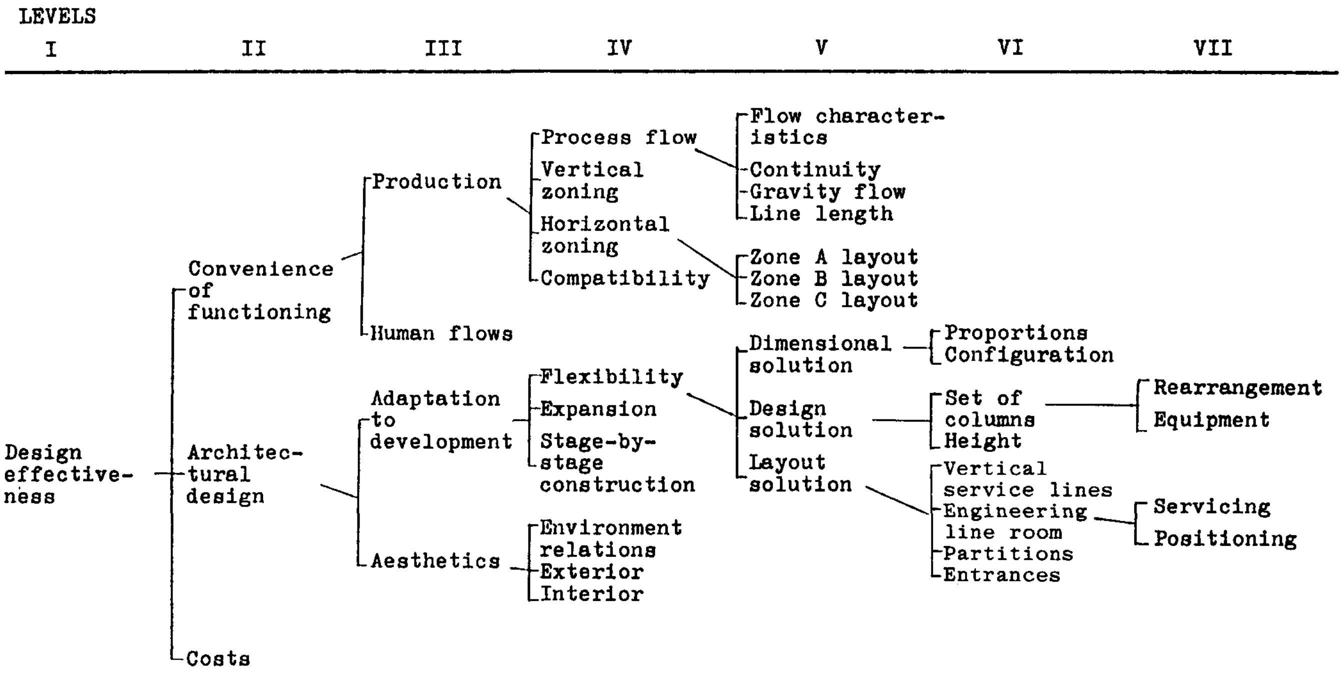


FIGURE 2: Hierarchical systems of criteria

Underlying the suggested method is a general methodological approach to non-recurring multiple criteria decision problems [3, 4, 5, 6].

In line with this approach, the decision-rule formulation technique must meet the following requirements:

1. It is necessary to retain the substantive qualitative notions in the course of transition from decision makers' and experts' information to general alternative evaluation.
2. The methods of decision makers' preference elicitation must conform to the possibilities of obtaining reliable information from people.
3. The procedure for decision makers' preference elicitation must provide for testing the preferences for consistency.

The developed technique for problem solution employs verbal ordinal criterion scales. Accordingly, this requires careful wording of quality grades on criterion scales. If the language of criteria and scales description is well-developed and is the natural language for a decision maker describing a choice situation, then its ultilization substantially improves the reliability and validity of elicited information.

In line with the decision method corresponding to the given problem description, the decision maker refers combinations of criterion estimates of the lower hierarchical level to one of the criterion estimates of the higher level, as if classifying the estimate combinations wherein the classes are the grades of a higher level criterion scale.

The ways of eliciting information from decision makers in such decision problems are sufficiently explored. Thus, a study was carried out concerning the behaviour of a group of subjects in referring combinations of estimates by seven criteria on binary ordinal scales to one of two decision classes [7]. It was ascertained that people quite successfully cope with this problem.

Reference 8 considers the limits of human informational capabilities in handling classification problems of this kind. The subjects' efforts were assessed by criteria of: transitivity, consistency, capability to develop complex strategies. An approximate decision maker's "limit to capabilities" was defined. Within the limit a decision maker is able consistently to express his preferences and employ complex strategies.

Beyond the limit he either displays a lot of inconsistencies or employs simplified degenerate strategies ('cut off' strategies) [6, 7].

As applied to the problem considered here, this method is quite acceptable.

There is another method of preference elicitation which, together with direct classification, can be used for testing a decision maker's consistency. A part of the criteria is fixed on the best (worst) estimates, and combinations of estimates by other criteria are classified. The fixed estimates are treated as a reference situation [4]. The comparison of classifications allows checking for inconsistencies and the independence of groups of criteria: if the generalised estimates by intermediate criteria are similar to different reference situations then these groups can be considered mutually independent. Otherwise it is necessary to classify criteria for all estimate combinations by other criteria.

When employing the given method of decision makers' preference elicitation, all combinations of primary criterion estimates (lower level criteria) will reduce to estimates on scales of three criteria: 'Convenience of functioning', 'Architectural engineering', and 'Costs'. The formulated rules of transition to the three general criteria reflected the preferences of the three decision makers: industrial engineer, architect, and construction engineer. However, the final choice of the best design alternative is made by the overall decision maker — the project manager.

The problem of choice, given a variety of interested groups (the group choice problem with a 'super-decisionmaker' participating) substantially differs from individual decision problems under multiple criteria. In this case the decision maker has to take into account the preferences of three other evaluators actively contributing to the problem solution. His aim is to coordinate their preferences on a variety of decision alternatives.

Let us stress once again that the super-decision maker's policy pursues an alternative acceptable to him and, if possible, to all decision makers of the lower level. Should there be a version considered the best by *all* decision makers, it will be approved by the super-decision maker. Otherwise the latter selects the best design from his point of view. In this connection we suggest the following choice procedure (see Fig. 3).

A Pareto set is singled out. If it consists of a single element, then this version is the best one (see block I). If there are several alternatives they look for a version with approximately equal deteriorations of quality for all participants which is offered to all lower-level decision makers as a trade-off (block 2). As for the super-decision maker, he explains to all his 'inferiors' that any other alternative will be unacceptable to at least one lower-level decision maker. Let us consider a case when the Pareto set does not contain such a trade-off version, i.e. all alternatives are much better for some lower-level decision makers and much worse for others (block 3). In this case the super-decision maker uses his own system of preferences to rank the alternatives. There are different methods (such as ZAPROS 4) or direct comparison of estimate combinations by three criteria. Thus, the super-decision maker defines the best design. After this he formulates new design specifications that would preserve the basic positive features of a previous version and would have superior estimates by other criteria. The improved version is presented for consideration to other decision makers. Should this alternative be unattainable, the super-decision maker takes his personal decision and demonstrates that a better trade-off is not feasible.

## A case example

The method for choosing the most effective design of an industrial building was tested on a bread-baking plant.

The program FORGS generated 150 versions of building design. Twenty-two versions were selected for preliminary analysis. Each one was provided with a design layout scheme generated on the program SHEMA.

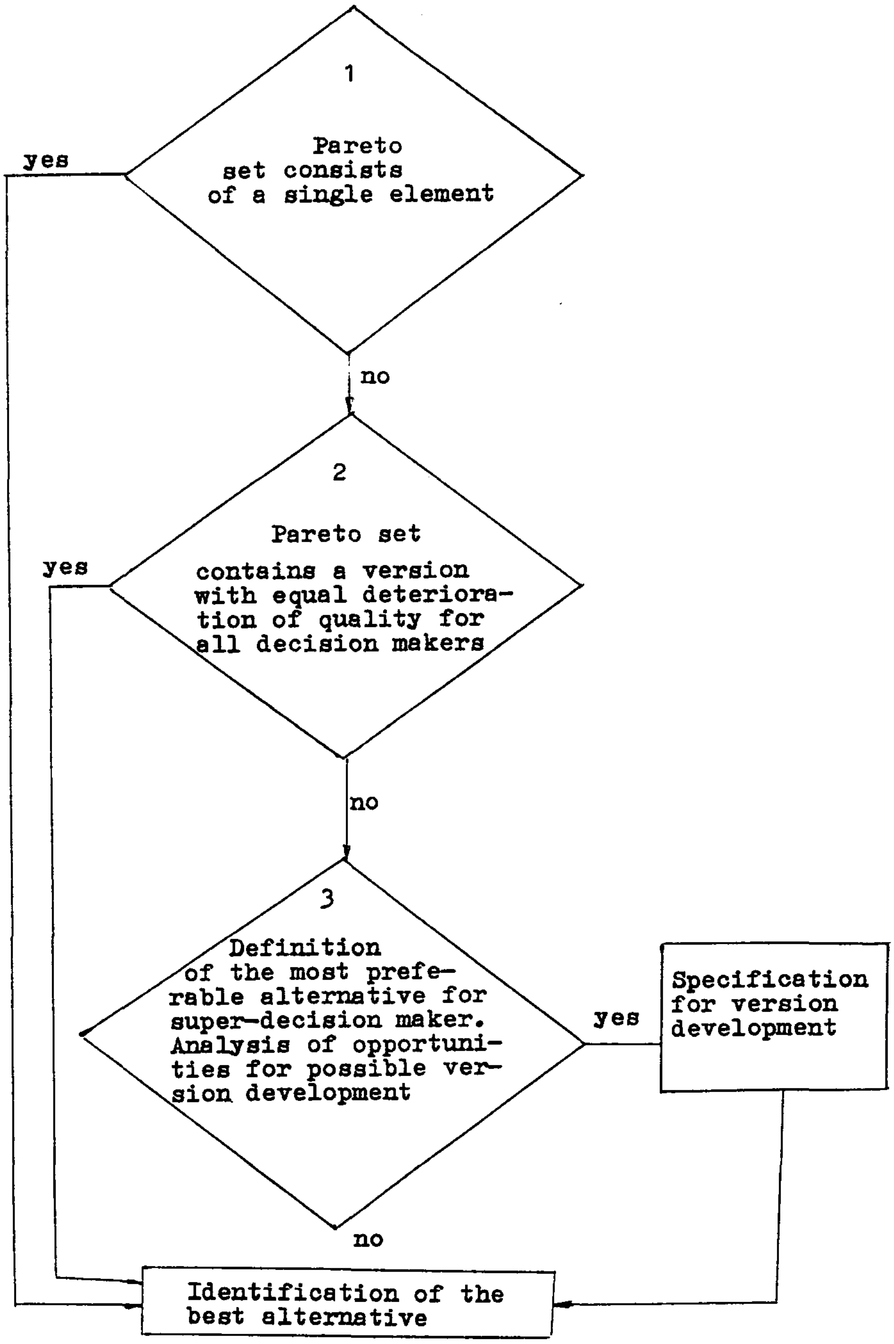


FIGURE 3: A choice procedure

The next step involved the drawing up of classification tables for a hierarchical system of criteria. The alternative evaluation with classification tables produced estimates of 22 criteria by three aggregative criteria, and within this set a Pareto area was singled out consisting of three elements:

| | *1st version* | *2nd version* | *3rd version* |
|---|---|---|---|
| 1. Convenience of functioning | 2 | 1 | 1 |
| 2. Architectural engineering | 1 | 2 | 1 |
| 3. Costs | 1 | 2 | 4 |

Each of these versions did not suit some decision maker at the lower level. The super-decision maker defined version No. 2 as the best one and formulated specifications for development of a version that would have a better estimate by the architectural cost criterion. The new, improved version was considered the best one.

## Conclusion

In constructing normalised procedures of practical choice, it is necessary to take account of both the capabilities of people to process complex information and the sometimes different, conflicting positions of people influencing the final choice. At the same time, practice requires that a final decision must be made.

The suggested approach to collective choice problems, given a super-decision maker, allows us to take account of all conflicting alternative estimates and to elicit information from each decision maker in a concrete fashion. It must be noted that the super-decision maker includes his preferences in with those of lower-level decision makers, and 'interferes' only when, without this, a decision cannot be made.

We believe that traditional decision theory considered an oversimplified division of all problems into those of individual and collective choice. There is a host of problems in between these cases. Formalisation of these problems and the search for rational procedures for their solution is a significant problem of modern decision theory.

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