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Substantiation of Decision Making Processes in Construction Management and Real Estate Development

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Abstract

Theories of how to support crucial decisions by optimizing weighted variables and aspects are widely known. The mathematical ground is well prepared and in no way distinguishable from hard-fact optimization. However, the transformation of soft factors into solid contributions to a virtual target function is mainly left to intuition. The fuzzy approach proposed by Zadeh during the seventies has turned out to be impractical and is recently more or less being ignored. Yet, methods of weighting soft factors based on different score systems, in fact directly derived from the Zadeh approach, are gaining ground. They are used e.g. in deciding for the complexity of planning tasks in Construction Management based on the HOAI as well as in analysis of procurement criteria, the definition of factors of success or in generally investigating network structures by means of cross-impact-analysis.
However, optimizing by the application of differential calculus and integrating difficult matters by simply translating advantages and disadvantages into virtual costs and profit, furthermore, the assignment of scores by more or less arbitrarily chosen curves seems a very inaccurate approach to proper judgement. Finally, so far resulting soft optima allow for no explicit evaluation and decision-making. Yet, this approach allows for analyzing the sensitivity of such a decision towards specific aspects and variables by backward modification, which is investigated in this article.
It turns out that backward analysis provides a much better access to the reasons and arguments for or against a specific decision and thus allows for well-reasoned judgement. In particular, the scope of proper application is demonstrated with BIM-Modeling based on multi-valued logics, including the meta-level modelling of control processes in Construction Management and Real Estate Development.

Keywords: Decision-Making; Control Processes; Procurement; Factors Of Success; Multi-Valued-BIM-Modeling.

1. Introduction

Decision-making has always been a matter of instinct based on experience and expertise of the responsible person [e.g. 12]. As all risk management issues finally rely on the supporting knowledge and estimation [23, 36, 39, 42, 43] and the impact of wrongly elaborated decisions is tremendous, efforts have been undertaken to place decision-making processes on more substantiated grounds [2, 3, 11] to ensure safe results [13, 17] as well as to protect the decision maker. This leads to the classical procedures of optimizing multivariable systems with respect to one target function in order to have at least some mathematical support for optimized decisions.

Standardized approaches are given by e.g. methods of multidimensional differential geometry, where for discrete situations well-known algorithms from simplex via transport algorithms and assignment algorithms of all sorts [9, 18] are available. They have in common to take into account a well-defined set of variables, subjected to a set of conditions and providing a singular or multiple optimal configuration vector with respect to an again well-defined target function [19, 27]. In previous times these algorithms were carefully engineered in order to save computing time and space of memory as the number of variables or conditions tend to become huge. Today, well-designed algorithms are available and computing power is in most cases no more a seriously restricting factor.

Thus, the question arises why still unsupported decisions are made and a significant number of such decisions is known to fail. This article intends to point out the real limiting factors which are located more in the deciders mind than in the methods applied and to propose an approach to additionally model and allow for judging these.

2. The Optimization Problem

2.1. *General Formulation*

Generally, a set of variables $\{x_i \mid i \in \mathbb{N}, i \leq n\}$ forms the basis for the description of all relevant criteria, which are to be obtained where the scalar target-function $G(x_i)$ is at maximum. Thus, a vector $x = (x_i)$ with dimension n in the space of states points to a general state. The vector $\bar{x}$ represents the optimum state if $G(\bar{x}) = Max$, as described e.g. in [1, 4, 8, 20].

The components can be of any kind, continuous like costs of crews, rents or performance parameters as well as discrete representing numbers of devices or workers to be used, numbers of lanes of a road or even be two-valued like a project to be accepted or rejected as a Boolean decision. There is even no need to construct these components to be comparable, as only the overall maximum of $G(x)$ is to be obtained.

The target-function needs to be of scalar type as only one criterion can be optimized which often causes conflicts since e.g. cost as well as duration need to be minimized. However, in this case time needs to be translated into cost resulting in a target-function representing not necessarily real cost but virtual cost, i.e. something unwanted which is to be minimized. The dependence on $\bar{x}$ can be linear or nonlinear with the only consequence of different approaches to be applied for calculation. Even the existence of poles only complicates the obtaining procedures but is no principal hindrance. Yet, the interpretation of the result might become more difficult.

Finally, a set of conditions might be defined restricting the space of solutions in some way. These are generally formulated as $F_r(x) = 0 \mid r \in \mathbb{N}$ or possibly as $F_r(x) \leq 0 \mid r \in \mathbb{N}$. The latter definition allows for no differential approach as it leads to discontinuous equations but reflects reality much better.

Depending on the structure of these equations, a multitude of methods and algorithms is available for strict or at least approximate solutions. A typical representative would be the simplex family, which allows for all linear sets of equations including inequations as conditions. A large set of problems can furthermore approximately be handled by linearization and then being subjected to simplex tableaus [7, 8].

2.2. *The Transformation Problem*

All required information needs to be formulated as explicit variables. This is not only needed for entering the criteria to the restrictions and to the target-function, but also for final interpretation purposes. Even very diffusive criteria must be returned as components of the resulting vector representing a clearly defined dimension in the space of states.

Therefore, even very fuzzy variables like the degree of traffic jam in a road network optimizing problem needs to be transformed to a value e.g. of virtual costs. Some can be translated or calculated as explicit cost like the lacking profit by vacancy of property but also the visual impact of vacant stores in a shopping center on the operative adjacent stores needs to be taken into account [45, 46]. Likewise, missing a target date might have financial consequences given by the contract as punitive damages but in addition to this, the damage on the reliability of the respective company needs to be valued and taken in [14, 21, 31, 38, 48, 49].

Such consideration turns out to be difficult and crucial but mathematical methods can only be applied if absolutely every aspect has been translated to meaningful values. This is in no way a mathematical problem but merely a typical engineer's task. Due to the lack of precision, explicit approaches are widely avoided and replaced by opinions, gut feeling and unfounded decisions.

2.3. *The Optimization Problem*

As long as the mathematical problem can be solved, a number of well-defined optima $\bar{x}_j$ can be calculated. The actual meaning of the given result is however to be interpreted by the engineer. This excludes probably meaningless just mathematical solutions e.g. complex zeroes or negative numbers etc. Yet even useful zeroes need to be judged carefully regarding their strength [34, 40, 41]. In many cases, flat optima are obtained indicating a very weak dependency of the target-function in close proximity of the optimum. Thus, a large deviation from the resulting optimal vector means no significant loss of optimality leaving the carefully calculated result rather fuzzy.

On the other hand, optimal vectors may represent a peak of the target-function allowing for no deviation without strong losses on optimality. Under such circumstances, considering several peak optima with different characteristics a second choice with an even lower value of the target function may appear more convenient as the respective variables cannot be kept safely on the required sharp value on the peak.

On this background, the mathematical procedures of optimization turn out to be the least problem; judging resulting peaks in terms of sharpness and considering the characteristics of the underlying respective variable regarding determination and controllability is the greater challenge.

Thus, the second derivative of the target-function at the zero not only provides the sign indicating a maximum or a minimum but also by its value informs about the averaged difference of loss of the target-function between sitting one and minus one units away from the zero. This is given by the specificity S of the optimum

$$S^{-}(\bar{x})\Big|_{i-\varepsilon} = \frac{\partial}{\partial x_i} G(\bar{x}-\varepsilon) \qquad S^{+}(\bar{x})\Big|_{i+\varepsilon} = \frac{\partial}{\partial x_i} G(\bar{x}+\varepsilon) \tag{1}$$

$$S(\bar{x})\Big|_i = \frac{\partial^2}{\partial x_i^2} G(\bar{x}) = \lim_{\varepsilon \to 0} \frac{S^{-}(\bar{x})\Big|_{i-\varepsilon} - S^{+}(\bar{x})\Big|_{i+\varepsilon}}{2\varepsilon} \text{ (Average of } S^{-} \text{ and } S^{+}\text{)} \tag{2}$$

Making use of this, the scales of the single components x_i are no longer insignificant but need to be comparable since an optimum wants to be judged with respect to all variables.

3. Fuzzy approach

3.1. *Fuzzy space of states*

In particular, as the dependency of a derived optimum needs to be analyzed with respect to a specific variable the quality of the definition and determination of each variable comes into play. Some calculable variables are well determined and therefore cause no severe problems. Yet variables given by feelings, image, mood or otherwise being only subjectively determinable become critical as well as situations where well-defined variables are affecting the target-function only in a virtual manner. In general, the problem of transforming fuzzy variables into well-determined values is required.

During the sixties L. Zadeh introduced Fuzzy Logic dealing with the problem of many decisions being not a clear yes or no but to some degree both of the two-valued space [32, 33, 29]. This concept is not only valid for logical decisions but also for the transformation of fuzzy information into determined variables and *vice versa*. The proposed concept approaches classical logic calculus as the values become sharp and can therefore be considered as an extension of the classical understanding.

A function $x_i = H(y_i)$ simply is intended to map the undetermined variable y_i to the well-determined variable x_i. According to Zadeh, *H* contains the agglomerated knowledge of experts and therefore is as good as possible a means to assign each value of x_i a "degree of truth", ranging from 0 to 1. Thus, more than a single strict assignment is available. On those functions H Boolean operations like AND, OR and NOT can be applied as the intersection, the union or the complement of the "truth"-values of the respective input in order to form more complex representations of specific variables.

$$H_{1\&\&2}(y) = H_1(y)\,\&\&\,H_2(y) = \int_0^\infty Max\big(H_1(y), H_2(y)\big)dy$$
$$H_{1||2}(y) = H_1(y)\,||\,H_2(y) = \int_0^\infty Min\big(H_1(y), H_2(y)\big)dy \qquad \overline{H}(y) = \int_0^\infty 1 - H(y)dy \tag{3}$$

The resulting set is a function of which the center of gravity is interpreted as the determined result.

$$y_{def}(x) = \int_0^\infty yH(y)dy \Big/ \int_0^\infty H(y)dy \tag{4}$$

This approach has been tried a lot but went finally more or less into oblivion, probably because the assumed consensus of experts forming $x_i = H(y_i)$ as a valid transformation is doubted for good reasons.

3.2. *Exemplary Usage*

However, the same is made use of, without mentioning it, in a wide range of well-known scientific approaches, where the particular transformation is commonly agreed on.

3.2.1. Questionnaires

Questionnaires are commonly used to explore markets by summarizing the personal opinions of a large universe of participants [e.g. 27]. Hence, the singular opinions, which are of no scientific weight, become a well-based description of the market if thoroughly chosen and evaluated based on a sufficiently large number of respondents. On this background even personal preferences can be asked and the results be transferred into strongly defined values. Basically questions refer to score systems e.g. a scale from "Like" to "Dislike" ranging from -5 to 5 scores which simply transforms a very fuzzy information to a well-defined value given by the center of gravity, i.e. the mean values. The linear or even nonlinear assignment of scores defines the transformation of the fuzzy "liking" to the result. In situations that are more complex several bits of fuzzy information are combined by the utilization of the respective Boolean operations.

3.2.2. HOAI

The definition of the difficulty of a design task for a planner within the HOAI is given as the assignment of the task to one out of five groups and if required to a similar score system allowing to measure the precise level of difficulty worth the respective remuneration [45, 47]. Even if more complex operations are not implemented here this system works the classical Fuzzy structure as introduced before. In particular, not so much the linearity but the granularity of the assignment is simply agreed on and not called into question.

3.2.3. Factors of Success

Investigating factors of success and their impact on success is also not really well defined. Factors need to be identified which have a strong and direct impact on success itself but can be measured and controlled during the runtime of a project while success itself can only be determined at the end of the project [24, 37, 44, 46, 48, 49]. Transfer-functions from the respective factors to the target-function of success are in general not explicitly given. However, success is controlled by making strict plans and the attempts to follow these as the only means to ensure success. Thus, implicit transfer-functions are assumed but never measured or checked out.

3.2.4. Procurement Criteria

As procurement criteria, the final price is only one issue to be considered. Additional aspects to be necessarily taken into account are clearly not directly measurable [10, 19, 22, 35]. There would be of importance e.g. experience of the project team, price difference to the best, size of company, experience with comparable projects, presence on the market, experience with customers, locality of company, history of company, contribution of particular personalities, degree of offered subcontracting, nationality, legal basis, size of market etc. Since these criteria are not available for measurement and additionally the modelled impact on the final decision is not of a mathematical type, a transformation-function is required. In some cases, this might be linear but mostly it will be strongly nonlinear. E.g. judging the wanted presence on markets neither none nor a full yes is wanted, but probably a carefully selected degree. Thus, a transfer-function might show a strong peak at some value in between. All criteria need to be subjected to transfer-functions and entered to a score system, which is weighted against the best price in order to pick the optimal offer.

3.2.5. Cross-Impact-Analysis

In Cross-Impact-Analysis the future situation of a network is investigated where the influence of nodes on other nodes is known [5, 6, 15, 16, 25, 28, 30]. In some – more physical - cases, impact factors are given by transfer-probabilities and are therefore accessible via respective measurements. Where networks are used to model social interactions e.g. representing participants of a project or just political or economic issues influencing each other the strength of interaction can no more be measured but must be estimated. Vester [26] makes use of a linear scoring system ranging from none to strong influence in three steps. In describing the particular meaning of a given score value nonlinear influence is integrated to the model. Finally scores are summarized i.e. ANDed or multiplied i.e. ORed for higher order evaluation of the network behavior.

3.2.6. Building Information Model

In a Building Information Model (BIM) every aspect of a building including its interaction with other elements is modelled and expected to automatically detect possible clashes. Mainly physical construction elements and their interfaces can well be described accordingly while operational aspects, e.g. the construction processes and the executing units, cannot be included directly due to the work contract type of interference. In order to gain reliable information about the operational behavior of a specific project network, fuzzy interaction given by coordination capabilities needs to be introduced to the model – making use of appropriate transfer functions. Due to the necessarily general character of these, only general parameters describing the operability of the project team will be returned [46] as the effectivity of the respective control processes.

4. Backward impact analysis

4.1. *Fuzzy space of states*

The need of integrating freely chosen transfer-functions for unmeasurable variables cannot be helped. However, they need to be defined carefully in advance. A much stronger test for their appropriateness would be to track them back from the location of the identified optimum by calculating the second derivative of the target-function, i.e. the specificity.

If the respective variable was measured in some existing units and just the transfer is being made arbitrarily combinations of triangle-functions are chosen in many cases to reflect multilinear interdependencies due to the lack of a better description. If additionally the unit of the variable is unavailable, at least verbal descriptions are existing, mapping expressions like “strongly”, “indifferent”, “most indifferent” “not at all” etc. to an amount of scores which are can be processed further [32, 33]. In any case, a well-defined set of possible input options is assumedly well described as the input originated once from it. This step of generating estimations is in general made in advance with no knowledge of the possible consequences of a particular selection. Proceeding along this sequence is important since otherwise decisions will be adapted to an expected or preferred result of the investigation and neutrality is no more guaranteed. Yet, the result can be tracked backward and provide a precise interpretation of what the actual meaning of a selection of a specific variable with respect to the optimal situation would be.

The second derivative of the target-function i.e. the specificity with respect to a imprecisely measured variable yields the exact description of the state if the optimum is deviated by a certain degree in the words originally defined for the variable in question and is therefore interpretable on this level. The left-sided first derivative yields the description of the lower selection together with the loss of optimality S^- while the right-sided is responsible for the higher selection S^+. The second derivative allows judging the overall sharpness of the peak as the sign-adapted averaged loss of optimality between one unit to the left and one to the right of the optimum.

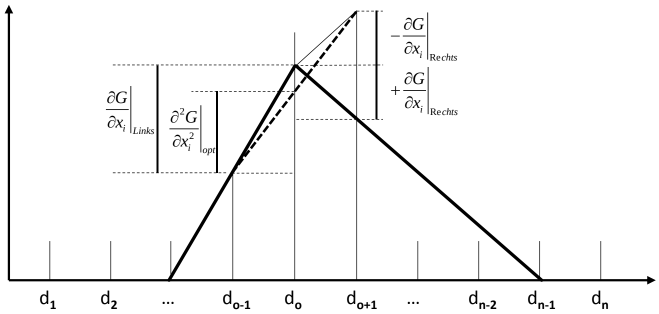

Fig.1. Interpretation of specificity at the location of an optimum.

Since each variable remains to be treated as a unique dimension to the problem, multi-linearity is only to be expected as a transfer-function introduced in advance being formed by a set of not matching triangle-functions as the result of several disagreeing experts. However, in this case the more complex transfer-function is well known and can be interpreted respectively, if not differentially the possibly by using discrete differences. All transformations to finally construct the target-function are unaffected as dimensions are being kept separately and the derivative with respect to x_i can be analyzed independently.

5. Conclusion

The proposed approach is expected to improve the solidity of decision-making by explicit judgement of the specificity role the respective variables play. It seems to be unavoidable to introduce soft variables, which cannot be calculated explicitly but need to be described by the use of verbal explanations. These need to be translated to describe their influence on the target-function, which is also done via soft transfer-functions. In former times, such procedures have been executed and the impact of the fuzziness was ignored relying on the assumption of a properly determined description.

Since this cannot be expected to be accurate, in general the reverse approach is required in order to prove the significance not only of the variable in general but in particular on the background of the specifically elaborated optimum. Thus, the relevance of the calculated optimum can be judged based on the originally introduced wording of the respective descriptions. From these procedures, some improvement on the stability and reasonability of decisions can be expected.

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