A multi-stage decision model for use at the early design stage of construction projects

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ABSTRACT

Problems normally associated with the need to examine large numbers of possible design solutions have been substantially reduced by the development of a computer-based decision model. By treating design as a sequence of decision-making processes, a model has been constructed which will aid designers in identifying the best solution from the full set of possible design solutions. The model is constructed according to principles normally associated with dynamic programming and is calibrated to both time and cost. The current version of the model is deterministic, although the development of a stochastic model is being explored. This paper describes the mathematics of the model and compares its performance with other methods. It is probable that more accurate forecasts of time and cost can now be provided at the early design stage of a construction project by using the model. An additional benefit of the model is its ability to guide the thinking of both designer and construction manager, particularly at times when constructability is brought into question.

Un modèle multi-étape pour la prise de décisions aux premières étapes des projets de construction

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MOTS CLEFS

Coût, Création de modèles, Durée, Ordinateurs, Prise de décisions esthétiques, Programmation dynamique,

SOMMAIRE

Les problèmes normalement associés au besoin d'examiner de nombreuses solutions d'élaboration possibles ont été largement réduits par le développement d'un modèle d'élaboration à base informatique. En considérant le design comme un série de prises de décision, on a réussi à construire un modèle qui aidera les dessinateurs à identifier la meilleure solution de parmi toute une gamme de solutions d'élaboration possibles. Le modèle a été construit d'après les principes normalement associés à la programmation dynamique, et étalonné selon la durée et le coût. La version actuelle du modèle est déterministe, bien que l'on explore le développement d'un modèle stochastique. Cette communication traite les mathématiques du modèle et compare sa performance avec celle d'autres méthodes. Il est probable que l'on pourra désormais fournir des prédictions plus précises de durée et de coût aux premières étapes d'un projet de construction en utilisant ce modèle. Le fait qu'il peut diriger la pensée du dessinateur et du directeur de construction, surtout quand la possibilité de construction est mise en question, est un avantage supplémentaire du modèle.

1. INTRODUCTION

It has been demonstrated by Ireland [1] that improvements in the quality of design solutions are likely to occur through generating more alternative designs and planning the construction process as part of the design. The introduction of construction planning early in the design process has also been proposed by Gray [2]. Gray suggests that although design affects construction planning, it is unlikely that construction planning could affect design. Improvement in the position demands techniques that are capable of evaluating the construction costs and times of large numbers of possible design solutions. It is probably true that such techniques are not currently available and that design teams are faced with balancing the numbers of design options with the time available. This enforced compromise overlooks the possibility of finding a feasible solution which is more acceptable to the client than the one finally proposed. The objective of this paper is to demonstrate that a model which takes account of both construction costs and times guides the designer to feasible solutions early in the design process.

2. SPECIFYING THE PROBLEM OF DESIGN

The problem of design evaluation under conditions of uncertainty is described by Dudnik [3] and Mitchell [4], where the difficulty of reducing computational effort into manageable proportions is the subject of mathematical optimization. Even so, the time needed to evaluate a modest number of possibilities rises exponentially. The problem which is characterised by 4x3x2 possible combinations would be computationally acceptable. However, to deal successfully with very large numbers of possibilities would require computational effort of an extraordinary magnitude. A means by which the computational effort might be reduced to more manageable proportions is, at least, superficially compelling. It is intended to reach this position by decomposing a single complex problem of design decision-making, over n-dimensional variables, into a series of more manageable one-dimensional sub-problems.

The optimization of designs by classical (mathematical) means has many proponents [5, 6]. Conversely, many have rejected classical optimization techniques as insufficient for determining a design solution which could be described as an optimum or 'best'. Acceptance of optimization as a sufficient technique for determining a 'best' in design is especially convenient, since the mathematics provide the necessary proof of the proposition. Zeleny [7] asserts that an optimum describes the comparison of decision options according to a single measure of merit.

Simon [8] suggests that certain cognitive limits lead decision-makers to frame their thoughts within rational boundaries and has devised the notion of satisficing as an extension and modification to the concept of optimization. However, Simon concedes that wherever possible, optimization should be undertaken in preference to satisficing. The danger is in attempting to attain pre-specified aspiration levels or goals without being cognisant of the full set of possible solutions. It is suggested this situation is commonplace within current building design practice. Designers often do not know what their maximised objectives are, since they are unaware of the extent of the full set of possible design solutions. Thus, in setting their aspiration levels lower than they might otherwise be, they are forcing themselves to accept a solution which is less than optimum.

Ackoff and Sasieni [9] have identified a major flaw in the use of satisficing. Their contention is that satisficing tends to concern itself with producing a feasible plan, which although not an optimum, is better than the reverse situation. This overlooks the possibility of obtaining the 'best' feasible solution and that optimality should take feasibility into account. Moreover, the approximate attainment of an optimum may be more desirable than the exact attainment of an inferior solution. Zeleny [7] also rejects the applicability of satisficing in certain instances and asserts that one can and should always optimize in a bounded sense; that is to say, being cognisant of the importance of a bounded rationality. Zeleny contends that decision-makers can operate on the principle of limited or bounded rationality only and asserts that neither maximisation nor optimization is incompatible with it.

3. CONSTRUCTION OF THE MULTI-STAGE DECISION MODEL

This Section examines the multi-stage nature of the decision-making of the designer. One way in which designs may be presented is as a grouping of specifications each relating to the several design elements of the building and reflecting the choices which the designer faces. In a simple illustrative case, it is possible to view the final design as representing just one selection from many possibilities. For instance, the choice of cladding, frame, wall and ceiling finishes might represent the combination 8x3x4x4, producing 384 possibilities, from which one combination only is selected. A sample of eighty office developments in the U.K. has revealed that the number of different design element specifications are sufficient to produce a feasible set containing many millions of possible design solutions. It may be possible to consider optimizing over each selection in turn to produce a theoretical 'best'. However, the interactions between each of the choices within the selections and the other design elements within the building ensure the unsafeness of this approach. The interaction of one design element with another is handled by mapping the proposed construction method. Therefore, it is probably more appropriate to redefine the combinatorial process around a network presentation, as shown in Fig. 1, where the design element specifications are largely equivalent to construction activities.

In its basic form, the network contains mutually exclusive activities only. In reality there may also be concurrent activities and others which are functions of the construction method. Of these other activities, there will be those which must be performed regardless. These fixed activities are termed AND conditions and are additional to the mutually exclusive OR conditions. It is possible to model exceptional cases and these are also shown in Fig. 1. The mathematical basis of each of the conditions encountered is described in Section 4.

The notion that each of the choices or activities is represented by a node is similar to the precedence diagram presentation of networks. The alternative method, activity on arrow, uses the links to attach activities, with the nodes serving as simple connectors. The model proposed here combines both concepts, but in such a way as to derive a more elegant means of portraying the relationships between activities. The proposition is that only those activities which fall on the least time or cost path will be adopted, whereas in CPM or PERT networks all activities must be performed. The implication is that the links are essential to modelling the different interactions between successor and predecessor activities. The relationships between each of the activities are accommodated by assigning values to the links between the stages.

In attempting to optimize designs, the intention is to seek out the least cost or least time solution. It may also be some combination of the two, such that it constitutes a balance of needs or compromise. Set against this background, the mathematics determine the 'best' solution. The contention that one can optimize certain characteristics of a design is, therefore, soundly based. The problem has been defined as n-dimensional and involves a model which decomposes into a series of one-dimensional sub-problems. This resultant series has sufficient in common with the original, whole problem for it to constitute a satisfactory, complete solution.

4. CONSTRUCTION AND DESCRIPTION OF THE MODEL

This Section describes the mathematics of the model and provides the necessary and sufficient conditions for the optimization technique used. The concept of decision CPM (DCPM) is described adequately by Crowston and Thompson [10] and Crowston [11], and is similar to the model proposed here. However, there are two significant departures. Firstly, both costs and times can be assigned to the links between states, in addition to the states themselves, where required to accommodate lead/lag times and costs. Secondly, a third variable, the dependency variable is provided, in addition to both state and decision variables, to handle situations where the sequence of two or more activities is an exception to the most common construction method (see Fig. 1).

The principles behind the construction of the algorithms are those associated normally with dynamic programming. Bellman and Kalaba [12] demonstrated that multi-stage processes could be decomposed into series of one-dimensional sub-problems. Woodward [13] outlines an approach to solving the particular class of problem identified as multi-stage decision-making under conditions of uncertainty using the computational approach of dynamic programming. It is important to note that dynamic programming is not a method which can be programmed on a once and for all basis to solve all problems of a particular class, but rather a way of thinking about solving certain types of problem. The proposed model draws on the strengths of dynamic programming without suffering many of its shortcomings.

The model comprises three distinct parts. These are dominated by recurrence relations, derived from the general form Eq. (11) in Cooper and Cooper [14], from which the several algorithms are constructed. The first, an algorithm for time, is paralleled at each stage by one for cost, and a third is introduced to handle the discrete time/cost trade-off. The model so constructed is capable of producing least time and least cost solutions with associated sets of activities. It is unlikely these two sets would coincide exactly and is a matter of finding a balance of needs or compromise. This is accomplished largely by the time/cost trade-off function, where the value of each day saved or lost is incorporated into the computations. In this way, the optimum cost is determined by calculating and comparing the respective times and costs of all possible policies (or outcomes), at all stages in the model. The algorithms make correct local decisions at each stage by selecting the least time and cost to complete the project. The value of each day saved or lost is used to set each cost against its associated time which is then translated into a theoretical total cost. If a state cost is returned which does not have the corresponding least time for the stage, the equivalent minimum theoretical total cost is calculated. This simple expedient treats each additional day, needed to perform a state, as though it was part of the real cost of that state. In the situation where no value is placed upon these saved or lost days, the 'best' selection would always return the stage with the least initial cost. The net effect is that the time/cost trade-off function is ignored.

A condition of the model's construction, is that the logic flow is acyclic. In addition, the solution is a backwards one, such that computation commences with the last stage and progresses stage by stage until the first is evaluated. The thinking behind the backwards approach is that at each stage the question is asked; which path will require the least time and/or cost to complete the project? This approach simplifies the strategy for determining actual start times by iterating on a stated completion date. Before each stage is encountered, each successor stage will have been evaluated. An iteration on the project's completion date is achieved once in each recalculation of the entire network. Dates are not calculated until the main algorithms have been applied completely.

The evaluation of the model, stage by stage, represents optimization over a one-dimensional problem. In the case of the times and costs of a set of mutually exclusive states, it involves minimisation only. Where concurrency exists, the algorithm differs. The time is determined as the maximisation of the minimum times for each set of mutually exclusive states. However, this introduces an over-accumulation of cost due to the double-counting of the costs carried back to that stage. To overcome this problem, Hindelang and Muth [15] used the simple expedient of selecting just one path to carry back cost, with the remaining sets having accumulated costs set to zero. There is no threat to the integrity of the model if this approach is adopted. The choice of which path to choose is an arbitrary one and is likely to depend upon personal preference.

5. PERFORMANCE OF THE MODEL

Previous attempts by Crowston and Thompson [10], Hindelang and Muth [15], and Robinson [16] have concentrated upon producing a generalised solution capable of handling a wider range of problems than the one presented here. Establishing the truth of a proposition, under the least restricting conditions possible, ensures that its solution will have the widest application possible. However, elaborate provisions, often made to include cases seldom met in practice, are unnecessary and many propositions can be proved more easily under more restrictive conditions. The proposition here is satisfied by a proof under sufficient (but not necessary) conditions, where the sufficient conditions are the ones met in practice. The proof can be verified by exhaustion using a notional number of stages and states.

A particular difficulty with methods and times for solving DCPM, identified by Crowston and Thompson [10], is the need to decompose the problem before algorithms can be applied. The proposed model assumes the use of low cost computer software in the form of a spreadsheet. The use of a spreadsheet makes the decomposition and manipulation of the model a relatively straightforward task. It is also possible to create a model which is associated more closely with the problem to be solved and, therefore, tailored to suit individual data availability and presentation preferences. Additionally, the model can be programmed directly by the user without having to generate computer code.

It is also possible to constrain the selection process at each stage and by iterating on the project's completion date, some degree of sensitivity analysis can be performed. A feature of the proposed model is that the exact optimum path through the network will not be determined until the algorithm encounters the start node. This is similar to Crowston and Thompson's method [10]. Presently, the optimum path is determined by inspection, although further programming of the spreadsheet may permit this to occur automatically.

In the present formulation of the model, it is assumed that unlimited resources exist and that states are not dependent upon any other beyond those in the adjacent successor/predecessor stages. The model is deterministic although the development of a stochastic version is being explored. In this version, the times for all variables are likely to have values selected from a pre-specified distribution. A minimum number of iterations will then be required, but unlike some simulation models, these will be contained within the partitioned stages. An advantage of this approach would be that sensitivity analysis could be performed at each stage.

6. CONCLUSIONS

The theory behind the proposed model has been applied successfully elsewhere. It has not been used in the early stages of design when innumerable possibilities have to be considered by the designer. The model overcomes the major difficulty of solving these n-dimensional problems by introducing partitioning (or decomposition). An advantage of the model is that computational times do not grow exponentially, but rather the times grow linearly in relation to the number of state, decision and dependency variables involved. The incorporation of construction planning during design, through the use of the model, provides a natural and direct means for examining the costs and times of possible designs. The combined effect of a more specific, less generalised approach to the solution and low cost, flexible computing ensures that problems of design optimisation, which were previously computationally unacceptable, can now be evaluated rapidly. This improves the decision-making of the designer and reduces the chance of a design being unacceptable from both a client and construction standpoint.

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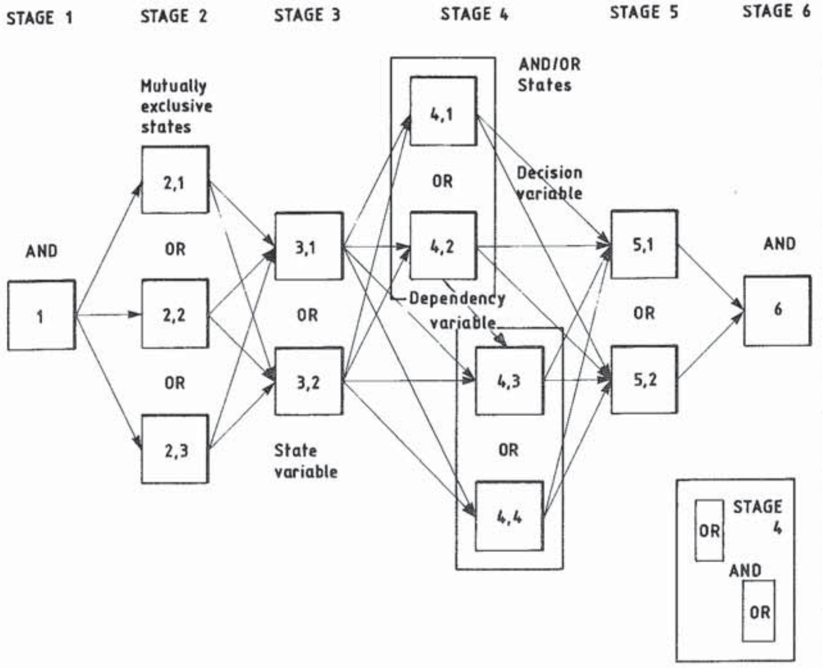

FIG. 1: SIMPLIFIED MULTI-STAGE DECISION MODEL

Computer Aided Management of Building Enterprises

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ABSTRACT

The paper presents a brief modular conception of a computer aided management system elaborated for a building enterprise, as well as the computer aided execution stages. The object adopted was to make up a socio-cybernetic system capable of significantly raising management quality in view of obtaining ligher economical performances. It may be achieved by creating a complex "instrument" that amplifies the planning, organizing, coordinating, control and adjusting capacity of those in managing position. This instrument is an Integrated Management System based upon man-computer symbiosis that works through a permanent dialogue between people and computer. The conception, achievement and utilization of this system is carried out in five stages, presented in the present paper; Global analysis of enterprise, using the method and technique of computer aided system analysis; Elaboration of conceptional outline, the logical and technical designing making use of computer aided system design; System construction by elaborating the programs and setting-up the computer equipment; Computer aided initiation in stages and modules; Conversational use of bank of data. Achieving highly automatized socio-cybernetic systems for data processing is a remarkably complex and difficult task requiring great intelectual efforts. The use of computer is efficient even from the system analysis and system - design stages. The computer is a skilled partner in further activities of system initiation by primary loading the data storage units and conversation use of the system, as well.