Expert Systems : A Paradigm Shift in the Quantification of Uncertainty in Decision-making for Construction Projects

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KEYWORDS

Construction modelling under uncertainty.

ABSTRACT

Deterministic methods of price forecasting, cost modelling and decision-making for construction projects do not adequately cater for uncertainty and incomplete information. This inadequacy may result in inappropriate decisions. Probabilistic methodologies, and in particular expert systems, a form of artificial intelligence, permit the explicit treatment of uncertainty and incomplete information. The contribution of these techniques towards the treatment of risk in decision-making may lead to more realistic decisions. The contents of the paper will cover the paradigm shift from determinism, the shift from inexplicability, describe the holistic concept of the paradigm shift and the partial shift provided by stochastic simulation, and the contribution to be made by expert systems.

Systèmes experts : changement du paradigme dans la quantification de l'incertitude dans la prise de décision en projets de construction

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MOTS-CLÉS

Modèles de construction sous l'incertitude.

RÉSUMÉ

Les méthodes déterministiques pour prévoir et pour modéler les prix et pour prendre les décisions en projets de construction ne prevoient pas suffisamment l'incertitude et l'information incomplète. Ceci peut avoir pour résultat des décisions inadéquates. Les méthodologies probablistiques, et en particulier les systèmes experts, forme d'intelligence artificielle, permettent le traitement explicite de l'incertitude et de l'information incomplète. La contribution de ces techniques pour le traitement du risque dans la prise de décision aboutira à des décisions plus réalistes. Cette étude discutera le changement du paradigme du déterminisme, et le changement de l'inexplicabilité. On décrira aussi le concept holistique du changement du paradigme et le changement partiel fourni par la simulation stochastique, ainsi que la contribution que peuvent faire les systèmes experts.

INTRODUCTION

The structure of the traditional procurement process for buildings imposes a division which tends to block the all-important data feedback channels. Each phase is seen as a linear, discrete process without due recognition of the overlaps, interdependency, nor the systems nature of the procurement process.

Attempts at cost modelling the design of buildings have hitherto focused on the modelling of the end-product (the building) as a discrete process. This facet is, in the writers' opinion, a major dysfunction of all existing methodologies, in that they ignore a systems approach to modelling. Researchers have attempted to create global solutions without first providing a sound theoretical base, and without understanding the inter-dependency and uncertainty existing between components and sub-systems. Indeed, this may be the cause of the paucity of success in the modelling of design/cost relationships.

In this paper the writers propose a resource (operations) algorithm - based modelling system which permits the treatment of alternatives and uncertainty, resulting in the ability to provide meaningful insight into design/cost relationships.

THE SHIFT FROM DETERMINISM

Stress has been laid upon the need for fresh thinking upon fundamental issues[1], rather than a modification of existing methods, and a prophetic call has been made for a "paradigm shift" from the questionable norms of traditional approaches in building cost research to new methods derived from proven theories and founded upon an adequate knowledge-base[2].

Considering the "shift" primarily as a research thrust with the objective of changing present practice, then one axis of the paradigm shift in cost modelling can be described as the shift from "historical determinism" to "stochastic variability". Traditional approaches to the provision of design/cost advice generally rely upon the use of historical price data to produce single-figure (i.e. deterministic) estimates of building cost, which are offered as predictions of future events without explicit qualification of their inherent variability and uncertainty. Such a deterministic understanding of the economics of buildings has been considerably criticised by academics such as Wilson[3] and Taylor[4].

If a deterministic approach to techniques of cost modelling is no longer valid, then the direction of the paradigm shift is clearly towards "stochastic variability".[5] A sound theoretical understanding of the phenomena of variability and uncertainty, together with the techniques necessary to examine and describe their implications, are available from the science of statistics and operations research. Probabilistic approaches to the economics of buildings have been demonstrated through the research of Wilson[3], Mathur[5], Spooner[6], Diekmann[7] and others.

According to Hardcastle[8], the fundamental weakness of traditional attempts to improve predictions in design evaluations has been the failure of existing communication documents to satisfy the criteria of an efficient information system. Following upon Hardcastle's recommendations, the major implementation problems facing building consultants are likely to be those of achieving adequate access to stochastically qualified information.

THE SHIFT FROM INEXPLICABILITY

The other major axis of the paradigm shift can be regarded as the transition from models which make no attempt to explain the system they purport to represent (as is the case with the majority of existing techniques), to those which are not only more explanatory, but which are also more representative of the manner in which building costs are incurred or generated, in that they make explicit recognition of the "process" aspect of building. Cost models are usually structured to represent "finished" buildings (or building components) and are thus design-biased as the emphasis is often more with ends than with means. Truly realistic cost models take into account, in a logically transparent manner, the economic implications of the way in which buildings are physically constructed, on the grounds that different construction methods significantly affect cost.

Such models must attempt to simulate the construction process, requiring the major operations to be identified, construction methodologies to be selected and an operational network to be derived and costed. These simulations will permit the likely results to be predicted more accurately and assist in identifying the degree of risk inherent in alternative construction methods.

A HOLISTIC CONCEPT OF THE PARADIGM SHIFT

Although the nature of the paradigm shift in techniques of cost modelling can be explained in the sense of a shift from historical determinism to stochastic variability, and a shift from inexplicability to logical transparency, a balanced approach to cost modelling requires the emphasis of the holistic nature of the new paradigm.

The concept of the paradigm shift is illustrated diagrammatically in Figures 1 and 2[9]. The existing paradigm (Fig. 1) provides the limiting framework for historical-deterministic models which are statistically questionable in the inferences they make, and which fail to explain the system they purport to represent. Such a paradigm adequately encompasses relatively few projects, similar in type, in a tight, over-constrained manner. This approach results in an increasing compulsion to justify the validity of the model by searching for "errors" in reality. Models only represent reality: they do not thereby become reality.

Through its emphasis on stochastic variability and explanatory understanding of construction processes, the new paradigm (Fig. 2) allows a far wider variety of often dissimilar projects to be embraced successfully in a more loosely-constrained fashion. If, as a consequence, this means that models are now considered to be less specific than was judged desirable in terms of the old paradigm, then it must be understood that this is the trade-off price for a more honest representation of reality.

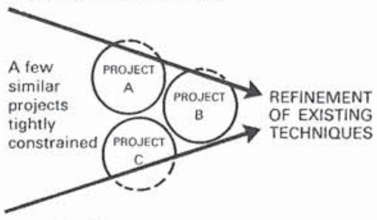

Fig. 1. The existing paradigm.

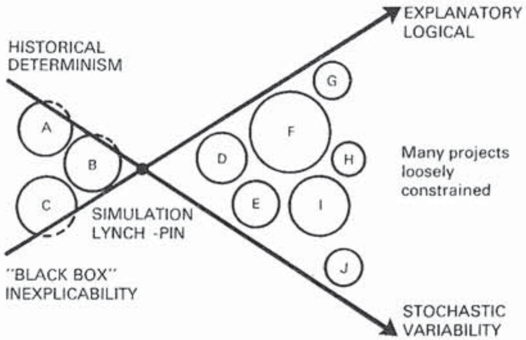

Fig. 2. The paradigm shift

The lynch-pin of the new paradigm, providing the underlying theoretical foundation for its two thrusts, is correctly identified by Brandon[2] as simulation. From the diagrammatic representation of the old paradigm it can be seen that continued refinement of existing techniques must eventually lead to a cul-de-sac in development possibilities (Fig. 1), whereas the adoption of simulation as the foundation for the new paradigm provides ever-widening opportunities for exploration (Fig. 2).

The requirement that design must reflect the construction implications is difficult to achieve in practice. It is suggested that by the testing of alternative strategies, it should be possible to determine the most appropriate method of construction having regard to both time and cost.

A PROCESS-BASED ALGORITHMIC MODELLING SYSTEM

Many attempts have been made in the past to model the process of construction in terms of networks. More recently, there has been growing interest in a probabilistic approach to such models (e.g. Bennett and Fine[10]). The underlying theme of these modelling attempts appears to be the desire to produce a modelling system which simulates reality as closely as possible, and permits the explicit treatment of the uncertainty inherent in the process. Traditionally these models have been derived as a means of enabling the more efficient and cost effective construction management of projects, with little or no attention being directed to the use of such models in the field of design economics and comparative costing (Baxendale[11], Legard[12], White[13] and Bennett and Omerod[14]).

Earlier work by the Department of the Environment in Britain, which resulted in the COCO system[15], showed an appreciation of the need to consider and model the construction process in exploring the consequences of design decisions; but this system of the early 1970's failed to incorporate mechanisms to deal with data variability and uncertainty. Nevertheless, its significance for the development of process-based algorithmic modelling systems for design economics purposes should not be under-rated, particularly in its establishment of basic principles for exploring the cost consequences of design alternatives.

More recently, research endeavours have focused on the application of artificial intelligence or expert systems to the discipline of construction economics, the work of Newton[16] and Brandon[17] being seminal in this regard. It does appear, however, that the value of this research may be diminished by the fact that efforts are being directed at systems relating to conventional practice i.e., related to the quantities of finished work produced, elements or components, rather than to the occurrence of specific events. Here again it is questionable whether or not the measurement activity is for the express purpose of modelling, resulting in the proposition that the data transformation process inherent in such a system results in a tenuous relationship between prices of finished work and costs.

The logical point of departure advocated by the writers is the amalgamation of an operational approach with an appropriate expert system, thus providing the cost-generative methodology with the ability to handle uncertainty and incomplete information, and not simply the variability of operational times and costs. This approach is thus not seen merely as the probabilistic extension of operational simulation using such techniques as Monte Carlo simulation, but rather as a holistic methodology attempting to encompass the imprecision of the system being modelled. Furthermore, it is evident that all too often construction researchers are captivated by the attractiveness of statistical and operations research techniques, without proper insight into the limitations and assumptions underlying the use of these techniques, resulting in models that are at best misleading and at worst deceptive.

More specifically, the hypothesised modelling (expert) system will encompass a computer-supported, operations-based method whereby building consultants can explore the operational consequences of the clients brief prior to detailed design. Following along from this, an interactive data-base for time, cost and operational data will permit the exploration of the consequences of design decisions. Quite clearly the model must contain a nested hierarchy of sub-models allowing for the successive stages of design. In this context design is not seen as a linear or sequential operation, but one which relies on the cyclical passage of detailing from coarse design to simulated construction and back again to design.

The major advantage of this system is derived from the ability of the expert system (and its associated knowledge-base) to cater for operational variables, this being done on a Boolean basis at appropriate directed arcs of the network, between nodal activities. Quite obviously the operational interrelationships and interdependencies existing between activities will have to be modelled; for example, in considering alternative frame components, the size of crane and the different labour and formwork requirements should be taken into account. The heuristic and flexible nature of expert systems allows the model to reason with judgemental knowledge as well as with formal knowledge of established theories.

Within the scope of operational alternatives, operational data, costs, etc. may be represented as probability distributions, thus enabling the model to cater for variability and uncertainty.

Added advantages to be gained from the adoption of such a system are that the system is consistent with the management of the construction process and the cash-flows. Indeed, it is not inconceivable that a resource/operations-based tender system could be incorporated.

CONCLUSION

Conceptually, the development of modelling systems for the purposes of design economics must spring from the desire for a closer representation of reality. This implies on the one hand the acceptance and appropriate treatment of variability and uncertainty, and on the other hand a more thorough representation of construction processes, each taking place within a suitable simulation environment. Expert systems, representing an important set of applications of artificial intelligence, and used in conjunction with operational/resource-based networks and techniques, offer the potential for a process-based algorithmic modelling system which could make a significant contribution to the decision-making process of construction projects.

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Expert System for Building Design

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Building Design, Expert Systems, Structure of the Representation.

ABSTRACT

At the DBECT at the University of Rome, an interactive Expert System for architecture is being implemented to supervise building design at every stage of development.
The System operates by checking the consistency of design choices against given sets of constraints, and by automatically checking the design process.
It is therefore an innovation with respect to current architectural software developed as specific design aids.
The System is based on a general representation of building objects (from components to the whole building) by means of semantic nets and a set of inferential procedures.
The general representation is developed by making explicit the relational structures according to which architects organize their knowledge about building objects.
To do this, the 'Frame' formalism is used: this is a knowledge representation technique used in the field of artificial intelligence.
It will then be shown that such an Expert CAAD System is a general purpose tool for architectural design, enabling architects to assess any constraint and/or building attribute by means of a declarative method, which in no way affects their own specific design methodologies.