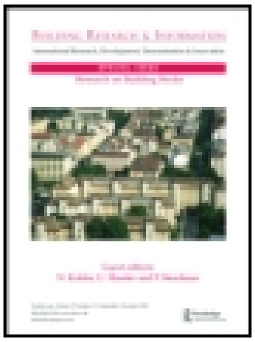

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Role of simulation in construction management

POSSIBLE APPLICATIONS OF SIMULATION EXAMINED IN RELATION TO CONSTRUCTION MANAGEMENT

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Key applications are identified by the authors which include decision support systems for managing real life construction firms and projects as well as tools and devices for teaching theoretical concepts in construction management, training and team building.

Les auteurs ont identifié les applications essentielles. Parmi celles-ci se trouvent des systèmes d'appui informatiques pour le contrôle de sociétés de construction et des projets pratiques, ainsi que des supports d'enseignement des concepts théoriques pour la gestion de l'industrie du bâtiment et la création et la formation d'équipes.

Keywords: Construction management, simulation, Monte Carlo, computer systems, construction contracts

The role of simulation in construction management

From the experience of the authors in designing and running simulations, and the experience of others who have written on the general theme, applications oriented simulation can serve the following functions in construction management:

- a decision support system in both strategic decision making and day-to-day management of real construction firms and projects;
- a vehicle for teaching theoretical concepts in construction project management;
- a tool for training and management and organisational development;
- a medium for disseminating findings of research to practioners in industry;
- a laboratory for conducting further research;
- an instrument for team-building;
- a public relations and recruitment exercise.

Decision support systems

The totality of decisions in construction is essentially hierarchical. At the highest level are the decisions pertaining to corporate issues made by senior and top management, e.g. the focus of the firm regarding the type of work undertaken by the business and the catchment area to be concentrated upon. At the lowest level are decisions about the essential motions required to execute a task.

Irrespective of the level at which the decision is being made, it is usually a common characteristic that the decision has to be made in a complex, uncertain and highly volatile environment. There are the questions of new materials, components and technologies, unforeseeable physical conditions, variability in human skills and motivation, changing economic and social climate, etc. to address. To counter these features there is a need for flexible tools which can assist the decision maker by making it possible to generate and analyse a range of courses of action and their likely outcomes. There is a general belief that computer-based simulation can best provide such tools within acceptable bounds of time and costs. This belief was endorsed by a panel of international experts formed to advise the National Science Foundation of the USA on new dimensions for computerized applications in the construction industry [1]. For example, with such a system the major participants in large and complex projects can meet in a kind of 'war room' scenario and simulate the management of their projects before they are actually commenced.

Teaching theoretical concepts

The traditional method of teaching theoretical concepts has been through lectures and discussions in a classroom setting. The shortcomings of this approach have been written about extensively [2]. The most frequently mentioned of these relates to the situation of learners being passive recipients of information. A second criticism is that the subject matter is taught in a linear and fragmented manner with little possibility or opportunity of effectively communicating the systemic and holistic nature of the subject matter. This shortcoming has a particular poignancy in construction management which is often taught as a number of different subject areas such as estimating, planning, cost control, financial management, and management of human resources. This fragmentation at the educational level is often replicated in working practices and professional divisions with the consequence that it is more often the exception than the rule for individuals to posses a holistic view of construction projects. It has been suggested that the generally blinkered focus may be the root cause of the industry's poor record regarding innovation in general and computer technology in particular [3].

The direction of thought of modern educational psychologists is that the solution to the shortcomings of the conventional approach to teaching is to provide what is referred to as 'action learning' or 'experiential learning'. These terms are used to describe a learning environment in which the learner is closely involved with and participates in the subject matter being taught. Perhaps nothing expresses the value of experiential learning more aptly than the ancient Chinese saying that:

> I hear and I forget
> I see and I remember
> I do and I understand

However, whilst several writers have explained the obstacles to providing experiential learning in real construction firms and projects [4, 5, 6], the ability of simulators to provide this type of learning without any serious commercial or physical risks has received widespread acceptance [7, 8].

Training and management and organizational development

The inadequacy of the priority placed upon training by British industry has been criticised continually in the national press. Although, of all the industries, the complexity, uncertainty and volatility of the construction industry makes it the most demanding in managerial skills, it has fared particularly poorly regarding management education and training. This view has been supported in a report of a joint committee of the British Building Employers' Confederation (BEC) and the Chartered Institute of Building (CIOB) [9]. The growing recognition of the value of management training has not been matched by the availability of effective training systems and techniques. However, simulation has recently offered a promising complement to the traditional training approaches.

Team building

Construction projects are characterized by organizational and professional diversity. Almost always, projects bring together organizations and individuals which have no history of working together. Even for individuals from the same organization they may never have worked together in the past. In this context communication becomes exceedingly difficult. Coupled with unavoidable conflict of interests and professional rivalries, creating an effective team out of such diversity can be a daunting task. The most common obstacles include:

- lack of understanding of the roles, language, and methods of working of other participants;
- incompatible social and professional attitudes and values;
- group sentience leading to rivalries and a general lack of empathy for others.

Social scientists have successfully applied simulation to combating these obstacles in similar conflict-prone situations such as marital breakdown, urban renewal and development programmes, and collective bargaining [2]. Having already discussed the effectiveness of simulation for teaching and training, the reasons for the success in these situations are not difficult to appreciate. Explaining the success of simulations systems as a social lubricant, Greenblatt [2] writes that in simulation exercises the supervisor can observe the dynamics of the group of interest and identify remedial action. Also, by structuring the feedback carefully, the motives and methods of working of each participant can be questioned constructively.

Dissemination of research findings

Like all academics, the construction management academic community disseminates the findings of its research through published papers, articles, and discussions at conferences and symposia. However, investigations have attributed the failure of practitioners to take up the findings partly to those conventional methods of dissemination [10]. Other research suggested that by incorporating the findings of research into a simulation system which replicates the decision making processes of practitioners, researchers can communicate and demonstrate their findings in a setting better suited to their assimilation.

A laboratory further research

There are a number of issues of great interest to the research community, e.g. the quantification of managerial skill, appropriate measures of the productivity of managers, quantitative relationships between managerial skills and corporate and project performance. By building decision rules on these issues into simulation systems, testing them against their referent systems, and modifying the rules until the simulation systems behave sufficiently close the referent systems researchers may be able to come up with some answers.

Public relations and recruitment

A long-standing concern of the construction industry is its 'muddy boots and hard hat' image. In most cases the public sees only the finished product whilst the challenges and interesting issues encountered in the production process remain shrouded in obscurity.

Through the use of a suitable simulator it should be possible to bring the reality of the management of construction closer to the public in general, and school leavers in particular. This possibility provides the opportunity to correct the wrong image and improving upon the industry's ability to attract talent.

Simulation studies and systems

Depending on one's conception of what constitutes simulation, its history may even be traced back to primitive man. The first genre of simulation in construction must have been scale models of the final products of the construction process. However, progress in formal simulation of the construction process itself is much more recent. For simplicity the formal studies into simulation of the construction process are discussed under the following headings:

- non-gaming simulation at the project level;
- gaming simulation at the project level;
- simulation at the level of a site operation;
- simulation at the corporate level.

Non-gaming simulation at the project level

This category of simulation studies has the common objective of determining the durations of construction projects. The first formal model of the construction process was the Gantt chart which started to be used towards the end of the nineteenth century. From then on there was no fundamental change until the late 1950s when the use of networks was introduced. The Critical Path Method (CPM) was developed by employees of Remington Rand and Du Pont. At about the same time the Programme Evaluation and Review technique (PERT) was developed by the United States Navy for application in its ballistic missile weapons development programme. The essential difference between the two systems was that only PERT explicitly recognized uncertainty in the estimation of the durations of the activities in the network. Whilst for each activity in a network CPM entailed the use of one deterministic estimate of the duration, PERT calculated it as a function of three different estimates: is most likely, an optimistic and a pessimistic estimate.

Neither CPM, PERT nor any of their variants was received by the construction industry with much enthusiasm [11, 12]. The reasons for this have been discussed extensively in the literature. Some of the barriers may have been eliminated by the use of computers and our better understanding human issues which influence the implementation of innovation.

A major criticism of the network techniques was that, in failing to take account of uncertainty in the estimation of activity durations, they were creating illusions of certainty. In 1963 Vans Slyke [13] introduced a technique for incorporating uncertainty into the estimates. The approach, referred to by various terms such as Risk Analysis, Monte Carlo Simulation, Stochastic Simulation, Stochastic Analysis, consists of randomly generating durations from assumed probability distributions, performing critical path analysis, and repeating the process an appropriate number of times. The final analysis produces not just one set of activities forming a critical path but a list of activities, each with a probability of being on the critical path.

The Graphical Evaluation and Review Techniques (GERT) which was developed by a team of researchers under the leadership of Pritsker [14–16] recognized a second dsimension of uncertainty in the conventional networks. This technique whilst treating activity durations as being stochastic also recognized that the interdependencies of the activities, i.e. the logic of the network, are also stochastic. The use of this technique by practitioners is also yet to become routine.

Subsequent researchers [17–21] have made further extensive refinements to the networks techniques. Woolery and Crandall [19], and Ahuja and Nandakumar [20] developed a stochastic network model designed to allow the scheduler to investigate different activity interdependencies and the effect of specific sources of uncertainty on activity and project durations. Bennett and Ormerod [21] developed a simulation system which incorporated the effects of uncertainty on both durations and costs. Interestingly, although based on the same approach, the basis of this system is the linked bar chart and not the conventional network.

There are a few commercially available software packages which produce probability distributions of projects duration and costs. The extent to which these systems are being used construction managers is as yet unknown. A commonly voiced concern about their use is that project participants, e.g. bank managers, developers, etc., who may not be sufficiently conversant with the technicalities of project management, expect definite statements of cost of time.

Some researchers [12, 22, 23] have pointed out that by the very nature most building processes are essentially flows of work squads and other resources through work locations and spaces. The most important task of site management is to arrange the sequence of flow and the logistics of the resources to produce a balanced flow at the desired rate of production. A balanced flow is one where there are no interruptions. Interruptions can occur when either a work squad is not available or a work location is not free for a squad to work on. These ideas are not new for they form the basic principles behind the well-known Line of Balance technique of scheduling. What was new was that these researchers modelled the construction process as queuing systems using queuing theory. Queuing theory is the mathematical study of waiting systems. The classic queuing system consists of customers waiting for cashiers at the supermarket. Using GPSS simulation language, Ashley [22] modelled repetitive unit housing as a number of crews queuing to carry out various activities in each house. In the jargon of GPSS the crews are 'facilities', the activities are 'transactions' whilst the activity durations are 'service times'. Building upon these concepts, Kavanagh [23] developed SIREN (SImulation of REpetive Networks), a computer mode of repetitive construction. The interesting thing about SIREN is that after entering the activities into the model using the concepts of queuing theory and the GPSS language a network of the project can be generated automatically. The Monte Carlo technique can then be applied to the activity durations.

Gaming simulation at the project level

The studies and systems [4–5] in this category have been aimed primarily at devices for teaching and training.

The literature reports on three major initiatives in this area.

Halpin's [4] CONSTRUCTO was designed to provide students on construction courses with simulated experience of managing real construction projects at the site management level. The players manage a project on a number of simulation periods which represent specific intervals in real time. For example, a month of real project may be represented by an hour of simulated decision making. In each simulation period a player is required to make decisions regarding staffing of the project, crew allocation, work calendar, and methods of recovery from schedule slippage. At the end of the period the system produced reports on works completed, costs incurred along similar lines as happens on real projects. The player then has to combat any adverse occurrences through decisions made in the next simulation period. The effect of uncertainty is simulated by the use of the Monte Carlo technique. The main sources of uncertainty recognized are weather and economic conditions.

Harris and Evans [24] developed a computer-based game for the training of site managers. Structured around a prepared line of balance schedule the game entails players running a road construction contract over a number of simulation periods. In each run of the game players are required to make decisions about allocation of crews to work tasks from a predetermined manpower pool, crew sizes, equipment allocation, hours worked, and materials availability. The decisions are processed by the system to produce feedback on schedule and costs of the simulated project. The effect of uncertainty and variability is simulated by adjusting the planned values of production by a random factor between 0.75–1.25. This factor is either selected by the supervisor of the simulation or generated stochastically from a uniform distribution. There is a similar adjustment for all uncontrollable factors which influence productivity. Out of sequence working results in wastage of the resources for work tasks which are prevented from starting.

Borcherding [5] developed a simulator designed to provide instruction to student managers on the management of disturbances on real projects. The sources of disturbances considered include weather, labour productivity, strikes, materials shortages and delivery. At the heart of this simulator, called CCS, is a model of a construction project in the form of activities and the resources required to run and complete it. The user is then required to run the project over a number of simulation periods by making decisions about the rate of consumption of materials, unit prices of resources, durations of activities, and productivity of labour, plant and subcontractors. Feedback for control purposes is determined by disturbing planned performance of the resources by random factor between 0.85–1.15 which represents the cumulative effect of all the factors, both controllable and uncontrollable, which affect the performance on real projects. CCS is also designed for use in the running of real projects.

Simulation of construction operations

This category of research into simulation has focussed on the construction operation, e.g. concreting, bricklaying, earthworks, etc. These studies have been of the classic operations research type and have been aimed at for providing systems and techniques for analysing, evaluating and even designing alternative methods of performing the operation concerned. A common example is the assessment of the least-cost combination of loader capacity and truck fleet to haul bulk materials for disposal at dump sites. The basic approach to this type of simulation involves the application of Monte Carlo simulation techniques to the estimated durations of the individual tasks in the operation as well as to durations of delays. The aim of this procedure is to incorporate the effects of uncertainty and variability on time and costs. This approach can be applied to work design by simply repeating the procedure for different methods of carrying out the task and selecting the most desirable.

The most widely reported research in this category was started in the 1970's and lead ultimately to the development of the CYCLONE (CYCLic Operations NETwork) and MICRO-CYCLONE. These systems are most suited for modelling operations which are cyclic in nature (the majority of construction operations). They have been used to simulate the concreting of frames for high-rise reinforced concrete buildings [25–29] and laying of asphaltic pavements [30].

Building on the CYCLONE system researchers [31, 32] in Stanford University have developed an interactive simulation system called INSIGHT (INteractive SImulation Using GrapHics Techniques). Using INSIGHT the operation of interest is recorded on videotape. The videotape is then played back and a flowchart of the operation drawn using computer graphics and CYCLONE notation. This flowchart is transferred interactively to a linked computer which determines the means and distribution of the duration of each task or delay in the operation. This data can then be used to determine outputs and costs. The analysis can be applied to the operation as actually performed as well as to hypothetical methods of performing it. Although proposals to incorporate expert systems to this type of simulation system have been made, achievement of this goal has not yet been reported in the literature.

In the UK, Pilcher and Flood [33] have developed a system called ICONS (an Interactive CONstruction Simulation) for modelling and analysing construction operations. A sub-system, ICONS BUILD, allows the user to build a graphical model of the operation using special symbols. After linking the model to data sets which define certain attributes of the operation, e.g. probability density functions of durations, the model is checked in readiness for analysis. The analysis part of the simulation is performed by another sub-system, ICONS RUN. The uses of this system are similar to those of CYCLONE and INSIGHT.

On-going research in Wolverhampton Polytechnic entails the building of models for materials handling in high rise construction using STELLA, a general simulation language [34, 35]. The approach of STELLA involves considering the system being analysed as a fluid flow situation involving storage tanks, valves and obstructions. By considering materials handling as a flow of the particular items from the point of delivery to the point of use it can be modelled in STELLA. Through experimentation with the model, the effects of variables which influence efficiency can be analysed. For example, in the case of bricks the effects of such factors as bricklaying crew sizes, productivity, palette size, crane type, and cycle times can be investigated.

Simulation at the corporate level

Finally, there are those studies into simulation of the issues raised at the corporate level, e.g. those concerning strategy, organization structure, the various functional areas of management, interaction of a head office with its various site, and project decisions commonly taken at head office. Unfortunately there has been very little reported research into simulation of this type of issues. Although Au and Parti [6] proposed simulators with wider objectives as far back as 1969 most of the subsequent efforts have been towards games which provide instruction on bidding.

Over the past decade the only major effort reported in the literature was started in the early 1970s in the UK by the second author of this paper [36, 37]. This research eventually led to the development of AROUSAL, an acronym for A Real Organization Unit Simulated as Life. AROUSAL is a flexible simulator which recreates the decision making environment in which construction companies are managed. Areas of decision making modelled by the system include:

- corporate strategy regarding type, size, and location of work to focus on;
- bidding;
- cashflow management;
- recruitment and termination;
- staffing of projects;
- tempo of working on contracts (normal or crashed);
- salary administration,
- etc.

Although based on the general philosophy of the other studies in this category the research underpinning AROUSAL broke new ground in two directions. Firstly, the organizational and human parameters of corporate performance which had been ignored in all other research have been successfully modelled. Secondly, experience of the use of AROUSAL by industry has demonstrated the possibility of achieving wider objectives with a suitably designed simulator, e.g. management and organizational development, team building, dissemination of new knowledge, and carrying out further research.

Building on the success of AROUSAL a long term programme of research and development towards the production of a simulator with a construction contract focus was started in the Department of Construction Management, University of Reading [38]. Following the modular approach adopted under the programme an advanced prototype of the sub-contracting aspects of the simulator has been produced [37]. This sub-module focuses on the decision making regarding the management of sub-contracted work and sub-contractors. Areas simulated in the prototye include:

- packaging of sub-contract works for tendering;
- selection of sub-contractors;
- supervision and coordination of sub-contract works;
- payment of sub-contractors;
- claims against sub-contractors;
- sub-contract termination.

Conclusions

This paper has examined the possible applications of simulation in construction management. The key applications identified include decision support systems for managing real life construction firms and projects and tools and devices for the teaching of theoretical concepts in construction management, training, team, building, management and organizational development, dissemination of the findings of research, carrying of further research, improving the image of the industry and recruitment of young talent.

The review of simulation studies systems indicated that there have been many initiatives focused on different needs in construction management. Most of these initiatives have been concentrated in the areas of operational decision making, teaching and training. A consequence of this narrow focus is that whilst simulation of the classical operation research type has matured simulation towards the meeting of the other needs at the project level is still very much in its infancy. The main constraints to the development of systems with wider functions include the primitive state of computers at the time and lack of experience in modelling qualitative issues. Advances in computer hardware and software technology and in our ability to model of non-quantitative issues suggests that the development of a simulator with wider functions at the project level is now very feasible.

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