

Construction Planning Models: A Review of History, Capabilities and Limitations

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Abstract

This paper critically reviews the various construction planning models developed by researchers and practitioners since the beginning of this century. The aim is to present an up to date review of construction planning models. The review provides a useful one stop reference for researchers during the early stages of related research, and practitioners wishing to evaluate their systems. The paper also describes current construction planning developments and comments on contractors' opinions regarding these developments.

This review is mainly based on current literature relating to different planning systems. In order to illustrate current planning practices within construction management, the review has included some of the results of a questionnaire survey conducted amongst the top 400 contractors in USA and top 100 contractors in UK. The review concludes that there is a wide variety of planning models, used by the Architecture-Engineering-Construction (AEC) industry, which range from simple techniques such as bar charts to sophisticated and complex models such as expert systems, simulation programs, CAD-based planning applications and integrated planning models.

Keywords: Planning models, Construction Planning, Construction management, Integrated construction environment, Integrated planning systems.

Introduction

Proper construction project planning is a vital management element required for the success of any project. Planning is a major component of project management as the definition of project management implies. Project management can be defined as the overall planning, control and co-ordination of a project from inception to completion meeting constraints such as time, cost, product quality and client satisfaction (The Chartered Institute of Building 1982, Pinto and Slevin 1988). Information has now become an essential element that should be handled properly in order to manage the ever increasing complexity of construction projects. This paper concentrates upon the planning aspect of project management and upon the importance and necessity of data management for satisfying various project constraints. Proper project planning is essential, hence the ever pressing need for effective planning models and/or applications. This is emphasized by the continuing development of computer models, to assist in the planning and control of construction projects.

It is important to point out that, recent developments within the Architecture-Engineering-Construction (AEC) industry have adopted the integrated approach to construction in general. Research on integrated planning models has thus been, and is being conducted by various researchers. Many researchers have already developed integrated construction systems that combine models of various construction phases or aspects. For example, Tah, Thorpe and McCaffer (1991) describe an intelligent integrated planning and cost estimating conceptual

model. Aouad, Ford, Brandon, Brown, Child, Cooper, Kirkham, Oxman and Young (1993c) developed an integrated construction model at Salford University, UK.

The merits and origins of integration have been discussed and reviewed by many scientists. A selection of world-wide contributions on the most up-to-date research in the integration of construction information, has been documented by Brandon and Betts (1995).

Even though a number of Artificial Intelligence (AI) techniques for generating construction project plans exist (Levitt, Kartam and Kunz 1988) they have their limitations, and many domain-independent planning models have failed to bring about useful results within the AEC industry. However, knowledge-intensive and domain specific planning systems have been researched and developed (Tah et al. 1991 and Brandon et al. 1995). These systems contain common practical knowledge on construction methods including knowledge of the impact of differing site conditions, resources, and other factors on production levels of individual activities (Tah et al. 1991). The systems have been useful and have met many of the requirements of the AEC industry.

This paper reviews the various planning techniques developed and used by practitioners and researchers in this field. These techniques have been classified, in this paper, under two categories: traditional methods and computer models. Traditional methods include Critical Path Method (CPM), Precedence Diagram Method (PDM), Programme Evaluation and Review Technique (PERT), Graphical Evaluation and Review Technique (GERT), Bar charts and Line of balance techniques whereas computer models include expert systems, simulation systems and CAD-based planning systems.

Traditional methods

Traditional methods of planning, i.e. bar charts, network techniques and line of balance can be fully computerised. These methods are very often used by researchers developing computer models to perform scheduling tasks. Aouad and Price (1994), in a questionnaire survey conducted among the top 400 contractors in UK and the top 100 contractors in the USA, found that bar charts and network techniques are the most dominant amongst all models used for construction planning purposes; and that the line of balance technique, which is mainly used for the planning of repetitive work, is not popular in the USA. Aouad et al (1994), also report that UK contractors do not seem to apply heuristics rules (rules of thumb) to construction project planning. They furthermore, show that GERT (Graphical Evaluation and Review Technique) is the least popular planning model in UK and USA construction industries.

Traditional planning models are discussed, in more detail, in the following sections.

Bar charts and Linked Bar charts

Bar charts, also known as Gantt charts, were developed around 1917 in the context of the First World War military requirement (Mordar, Phillips and Davis 1983). They are generally defined as a work programme charts showing the duration of activities plotted to scale against a time base. Construction managers use work programme charts (schedules) to effectively manage construction projects.

The only difference between a bar chart and a linked bar chart is that the former does not show any connections between activities, whereas in the latter links between activities are used to show constraints that exist among these activities. Such constraints establish the logic of the work programme. The Bar chart can be used as the only scheduling tool, or it can be used as a means for the presentation of schedules developed by other techniques, e.g. CPM. Bar chart techniques are used by 97% of UK construction planners and 87% of USA construction planners (Aouad et al 1994) because they are:

- easy to construct;
- useful in handling the project resources, e.g. resource aggregation and resource leveling;
- easily produced from CPM and PERT networks when computerised; and
- appropriate as means of communications between groups involved in the construction process.

However, bar chart planning techniques have their own problems and limitations, particularly for large projects. For example project activities interdependencies, which are essential for establishing the logic of the work programme, are not clearly shown and bar charts are tedious when updated manually.

Network techniques

Network techniques were developed in the late 1950's and brought into the construction industry in the early 60's to control complex projects (Arditi 1983). A network (logic diagram) can be described as a diagram that graphically depicts a project. The diagrams use various symbols to depict the project tasks and the logical relationships between these tasks (Willis 1986). In other words, these diagrams are graphical representations of the actual relationships among any project activities. There exist two types of networks (logic diagrams) namely, activity on node and activity on arrow diagrams. In general, logic diagrams consist of nodes and arrows. Numbers and words are used to label the nodes and the arrows in the diagrams. Project activities could either be depicted on the nodes or on the arrows of the logic diagrams, hence the two types of network diagrams, namely activity on node network diagrams and activity on arrow network diagrams. In these diagrams, the node at the tail end of the arrow is the I node, whereas the node at the head end of an arrow is the J node. Production of the project schedule, requires network analysis to be carried out. This involves analysis of project task data and the logical relationship between the project tasks, in order to workout values or calculations needed for the preparation of the schedule. CPM, PDM, PERT and GERT are good examples of the network models.

CPM (Critical Path Method)

The critical path method was developed in 1957 by Kell and Walker at Dupont (Dean and Chaudhuri 1980). CPM is based on the analysis of activity on arrow project network diagrams whose nodes represent points in time (events). CPM works out the critical path through the project network diagram. The critical path represents project tasks that must be completed on time if the project is to be completed on schedule. The tasks on the critical path are generally known as critical tasks (Willis 1986). Since the advent of CPM, a number of articles have been published, some criticising it as unsuitable for construction projects (Birrell 1980), (Jaafari 1984), (Kavanagh 1985); and others favouring it as more than appropriate (Mahony 1988) and (Neale and Neale 1989). Mahony (1988) states that one of the major advantages of CPM is that, for the first time logical thinking about the sequence of

events which are to take place on site is incorporated within the model. Such incorporation is a major requirement for the successful planning of construction projects. Neale and Neale (1989) strongly argue that CPM is a powerful control tool ideal for construction projects. Aouad et al (1993), report that 67% of UK and 76% of USA respondents to their survey questionnaire, thought that CPM and PERT techniques were suitable for construction work. The reasons given by constructors for supporting CPM include:

- CPM and PERT were originated in an industry similar to construction;
- the techniques provide effective means for stating the sequence of activities;
- they are number crunchers and can be used to fit properly;
- they provide suitable means for tracking progress and evaluating the entire project;
- CPM is a planning and organising tool that is flexible enough for use in many applications or industries; and
- scheduling systems can be adopted to many situations.

Although many researchers favour the idea of using CPM for construction projects, as more than an appropriate technique, some researchers reject the technique. Birrell (1980) believes that the CPM method was created in the military industrial environment and cannot be used for construction projects as they are not of national importance. Jaafari (1984) argues that the assumption made by CPM, that project activities have fixed time and discrete nature, are unrealistic, especially when repetitive units or linear projects are to be constructed. Kavanagh (1985) describes CPM as a poor model for the construction process, suggesting that site superintendents think of work crew and not activities.

Some Contractors who do not favour the use of CPM for construction projects, are advancing the argument that the mechanics of correctly making the logic flows, is very time consuming; and that construction does not lend itself to network techniques other than in great details (Aouad et al 1993).

We, as a result of this review, assert that there is nothing wrong with the CPM concept when applied to construction projects. Indeed, most computerised construction planning models developed in the last few years have adopted CPM as their planning, scheduling and controlling tool (Hendrickson, Zozaya-Corstiza, Rehak, Baracco-Miller, and Lim 1987), (Alshawi 1989) and (Morad and Beliveau 1989).

PDM (Precedence Diagram Method)

The Precedence Diagram Method (PDM) is used widely within AEC industry (Willis 1986). PDM provides facilities that enable schedulers to specify much more complex relationships between construction tasks than does the CPM. PDM, for instance, allows straight forward introduction of time delay into the diagram. PDM is based on the analysis of activity on node network diagrams. Arrows in these diagrams represent logical relationships between tasks. PDM allows more complex logical relationships between tasks, in a construction project, to be represented. Unlike CPM which can only depict one logic relationship (i.e. precedent relationship) between project tasks, PDM can depict four types of logical relationships, namely start to finish (SF), start to start (SS), finish to start (FS) and finish to finish (FF). These relationships define the delay that must occur between either the start or finish of one activity and the start or finish of another activity in sequence.

PERT (Programme Evaluation and Review Technique)

PERT was developed in June 1958 by the US Navy to Control the Polaris missile project (Dean et al 1980). However, PERT has features that are applicable to construction management. PERT is based on the analysis of activity on arrow network diagrams. It is important to note that PERT was developed as an event-oriented technique, whereas CPM was developed as task oriented technique (Willis 1986). PERT can, nevertheless, be used to calculate task durations. Willis (1986), describes events as points in time that are separated by some form of activity or even inactivity.

Using PERT, one can estimate the expected project duration and the probability of completing the project within a particular time period. In other words, PERT assumes a deterministic network and a stochastic activity duration by requiring three time estimates: the most optimistic, the most pessimistic and the most likely times. Once the expected duration for each activity is worked out, the PERT values are then computed, using a method similar to one used in CPM, hence the use of CPM/PERT notation by some researchers to refer to any of the two scheduling techniques because of their great similarities.

PERT is more popular in the UK construction industry (Aouad, et al. 1994). However, when compared with CPM, PERT is less widely used, probably because the three time estimates are not required by the CPM techniques (Aouad, et al. 1994).

GERT (Graphical Evaluation and Review Technique)

GERT is a network model which can handle complex modeling situations in the sense that it allows for a greater flexibility and uncertainty to be included in the structure of the network. GERT combines flow graph theory, probabilistic networks, PERT/CPM and decisions trees (Moder, Phillips and Davis 1983) and (Dean, Chaudhuri 1980). GERT is not used by any contractor in the UK and only by 2% of the USA contractors (Aouad, et al. 1993). This low percentage is attributed to the fact that GERT is only considered appropriate for a special kind of projects, such as research and development, where the future work to be performed is likely to be uncertain.

Line of Balance

This technique was originally developed to help in the planning and control of manufacturing processes. It was then adopted in the construction industry (Gessesse 1989). The line of balance method is mainly used to plan the construction of similar items. Examples of construction applications for which line of balance planning methods is used include pipelines, bridges, high-rise buildings with repetitive floor construction, tunnels, etc. Using methods other than line of balance method to plan such construction projects leads to complexity in network diagrams due to the inclusion of the details of all the repetitive units involved; the network may thus, prove expensive. Line of balance eliminates unnecessary network complexity.

Production diagrams, which are network diagrams representing basic construction programming logic of one repetitive unit, are used in the line of balance method as a basis for producing target and progress charts. The technique used in the line of balance to produce the targets and progress charts is simpler than network analysis methods (Pilcher 1992).

The result of a survey (Aouad, et al.) showed that 27% of UK contractors use line of balance method, whereas only 10% of USA contractors use this method. Line of balance is thus more popular in the UK than in the USA.

To summarise, traditional planning models, particularly CPM and PDM, are the most widely used planning models by the construction industry. Traditional models are, in general, appropriate for carrying out effective project management. The survey (Aouad, et al. 1993), referred to in this paper, has confirmed that various contractors consider traditional planning models, e.g. CPM, to be more than sufficient to handle construction projects. However, as construction sites are becoming more complicated and congested and information has become more important than ever before, it is logical and imperative for researchers to develop more reliable and realistic construction planning models to fully meet the new construction requirements. The new models are based on recent advances in information technology. These models are discussed in the next section.

Computer models

During the past few years, researchers and practitioners of construction planning have developed computer models to assist in the planning and controlling of construction projects. Our review has found that most of these models have adopted CPM as their scheduling tool. Expert systems, simulation, integrated and graphics techniques are examples of these computer-based planning models.

We should point out that the contractors survey (Aouad, et al. 1993) has, however, revealed that there is some lack of knowledge by construction personnel of the techniques afforded by computer models. It also found that 14% of the USA and 25% of UK respondents have not heard or were not familiar with the terminology associated with expert systems and simulation techniques. This finding highlights the importance of training and educating construction professionals in different aspects of information technology. Another finding was that, 55% of USA (41% yes and 14% possibly) and 45% (15% yes and 30% possibly) of UK contractors believed that :

- computer models could be applied to the construction of standard works (warehouses, factories), small developments and temporary works, and large contracts with large number of sub-contractors.
- computer models are useful for modeling different crane access, activity breakdown structure, manpower analysis, what if scenarios, visualisation of the planning process, determination of problematic scheduling areas, and better approximation of actual conditions and procedures.

Some contractors are nevertheless, not in favour of using computer models for planning purposes (Aouad et al 1993). Their judgment is based on the view that

- there are too many variables in productivity and weather;
- the models are too sophisticated and inaccurate;
- time available to the contractor is not enough; and
- planning a contract is an individual operation.

The main computer-based construction planning models developed in the past are presented below:

Expert systems

An expert system is a computer program which simulates a consultation between an expert of a particular field and the non-expert (Wijesunder and Harris 1986). In the field of construction planning, many expert systems have been developed, mainly in the UK and USA. Levitt and Kartam (1990) presented in 1990, a snapshot of expert systems in construction and engineering at the end of the 1980s. The expert systems, in construction management, reviewed by Levitt, et al. (1990) include Plattform III, PROPICK, SAFEQUAL, DISCON, HOWSAFE, TSA, PREDICTE, Expert-MCA, CRIS and ELSIE, BREDAMP, PUMP PRO, ISIDC, OARPLAN, etc.

This paper presents, in the following sections, a review of other major expert systems.

Construction planex

Construction Planex is a prototypical knowledge intensive expert system for construction planning. This system was developed by Hendrickson, Zozaya-Corstiza, Rehak, Baracco-Miller, and Lim (1987) in the USA to generate activity networks, cost estimates and schedules. It was designed to plan modular high rise buildings including excavation, foundation and structural construction. In this system, the different design elements are identified, then tasks or elements activities to install these design elements are assigned. These tasks are then aggregated to form project activities. The construction planex models uses the CPM techniques to handle the scheduling task. The main limitation of the construction planex model is that, only precedence relationships derived from physical relationships among building components are accounted for. The interaction of trade and its effect on activity logic is not considered (Echverry, Ibbs and Kim 1989).

Ghost

Ghost which is a prototype knowledge based system for network generation. It was developed at the MIT by Navinchandra, Siram and Logcher (1988). It takes a set of activities as an input and provides a schedule as an output by assigning precedents among activities. The system assumes, at the start, that all activities can be done simultaneously, then according to the stored knowledge the network is modified whenever activities can not be done in parallel. Currently, the Ghost system does not consider resources and does not support activity duration determination.

MIRCI (Management Interface for the Construction Industry)

MIRCI is an expert system developed in the UK by Alshawi (1989), to assist in generating and scheduling construction activities. The major aim of this system was to develop a facility which automates the establishment of a construction solution from a given design proposal. The system integrates micro-based expert systems, project management technology and database management systems. MIRCI uses the expert system to generate construction activities and their precedence. This information is then passed on to the project planning system, which generates a schedule in the form of a network. Communication between various components of the system is carried out via a common interface, which consists of a database. The work undertaken by Alshawi demonstrates the feasibility of using microcomputer technology to develop intelligent integrated applications for construction planning purposes.

CONSAS (Construction Scheduling Analysis System)

CONSAS is a PC-based expert system developed by Ibbs, C. W. and De La Garza, J. M., to analyze construction schedules (Kahkonen 1989). As in the MIRCI System (Alshawhi 1989), the CONSAS model is based on the idea of integrating database management, project management and expert systems. CONSAS can be used to analyze schedule proposals; one module of this system is aimed at evaluating the accuracy of activity duration estimates.

Platform

The Platform model was designed at Stanford University by Levitt and Kunz (1985) to assist in the updating of the design and construction of offshore drilling platforms. The system was built using the Intellicorp Kee environment using the Xerox 1108 computer. The platform model has proven the validity of the usage of hybrid artificial intelligence environment for the support of construction scheduling. This approach can also be used to generate construction schedules.

FEPP (Finite Element Project Planning)

The FEPP system was developed at Nottingham University by Sirajudin and Mawdesley (1989). It is a knowledge-based system for the recognition of work required for construction. In the FEPP system, the site is divided into a grid of rectangular charts; the grid size depends on the details levels. Drawings used by FEPP can be interpreted to determine the elements of work at any level. Following this work recognition stage, a scheduling process is needed to determine the order in which the work must be done and how it will be done using the available resources. This is achieved by using algorithmic and knowledge-based procedures. The FEPP could be used to establish an intelligent construction work recognition system. The main limitation of this model, is its lack of automatic or computerised means of interpreting the drawings used to determine the elements of work at any level. The model, therefore, needs further enhancements.

Time

This model was developed at Reading University by Gray (1986). The main aim of the Time system was to pass the knowledge used by the construction planner to the designer through an intelligent knowledge-based system. Gray (1986) gives a clear explanation how schedulers use heuristic rules to break down the construction of any facility into activities based on the type, function and location of the work. The main limitation of the Time system is its lack of an object oriented capability for describing the building components.

Other works on expert systems in the area of construction planning include those of Warszawski et al at the National Building Research Institute in Israel (Warszawski, Pashkovetzky 1990), and of Waugh at Stanford University in the USA (Waugh 1989).

Simulation Models

Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system (Paynes and James 1982). The major construction planning simulation models developed in the past, have been compiled and are presented below.

SIREN (Simulation of repetitive networks)

Siren is a computer model which was developed by Kavanagh (1985) at the University of Missouri-Rolla to simulate the construction of repetitive structures such as the construction of multi-storey buildings. This model requires the user to input a precedence diagram of the repetitive unit and additional sub-networks of the non repetitive elements. The computer would then generate the whole network. The model simulates the various crews as they queue to implement their associated activities. The outputs of the model are presented in terms of working schedule, cumulative cost curve and statistics on crew and equipment utilization. Siren is run on a remote mainframe which accepts data from a site-based IBM PC. The main limitations of the system are the lack of flexibility in changing the crew size during the project and, the lack of intelligence as the system does not contain rules to generate the sequence of work.

PRODUF (Project Duration Forecast)

This model was developed in Canada by Ahuja and Nandakumar (1985). The main limitation of this system is that it is only used on mainframe computers. Its main task is to simulate the expected occurrence of the uncertainty variables of the project. The PRODUF system can be used to: a) forecast probabilistic project completion time; b) determine criticality index; and c) measure sensitivity of an activity to uncertainty variables.

Stochastic Network Model for Planning Scheduling

Whereas ordinary simulation models include some degree of simplification, stochastic networks accept most data describing project activities in the form of a distribution. Thus, stochastic networks can be considered as more advanced and sophisticated simulation techniques. The stochastic network model described in this section was developed by Woolery and Crandall (1983) at the University of California. This system is based on Monte Carlo simulation techniques. The input consists of a time distribution for the activity under optimal conditions and a series of time distributions for various problems which lengthen the activity completion time. The output of the network model is a decision criteria which demonstrate the possible variation in outcomes rather than relying on a single point estimate.

Examples of other simulation programs dedicated to construction planning include the Construction Project Simulator developed at Reading University (Kahkonen 1989).

Integrated and Computer Graphics Models

The use of integrated and computer graphics models to assist in the planning and controlling of construction projects has been recently considered. These models involve the use of CAD systems. Aouad et al (1994), reported that contractors have started to realise the benefits integrated systems can offer to construction management, particularly to construction planning. A substantial number of contractors in the UK and the USA view CAD systems, within the context of integrated construction management, as a very useful and desirable starting point for construction planning.

Some of the main benefits a CAD system can offer to construction planners include:

- the ability to simulate the construction process on the computer screen; 41% of UK and 95% of USA contractors share this view (Aouad 1994).
- the ability to visualize the building model and construction site, to account for site restrictions and equipment and trade interactions; 79% of UK and 72% of USA contractors agree with this view (Aouad, et al. 1994).

Construction researchers and practitioners have developed and still are developing CAD-based integrated and computer graphics models to aid the planning of construction projects. The major CAD-based planning models have been reviewed and are presented below.

Retik, Warszawski and Banai (1990)

Retik et al (1990) of the Israel Institute of Technology, have developed a model to assist in construction scheduling. The input to this computer graphics based system consists of a geometrical representation of the structure to be erected and a schedule for the erection of its main components. The program outputs a graphical representation of the total schedule. The system can also produce reports on construction status. The developers of this system have used two inter-related packages: Sched and Draw for the tasks of scheduling and modeling. The 3D computer graphics package incorporated within the system, enhances the presentation of the project and permits the planner to view his/her structure as it will look during construction.

Atkin and Gill (1986)

Atkin et al (1986) at Reading University, have configured an experimental integrated system to provide information for management purposes, besides producing drawings. This system is based on the idea of integrating computer aided design and relational database management systems. Details of specifications, costs, durations and resources are stored in the database system which accepts graphical data from the CAD model and relates them to their associated non-graphical attributes. In addition, the graphical data input stage includes a bar chart which is used to produce a schedule of durations for the work packages held in the database management system.

The model was developed by Atkin and Gill (1986) after a thorough investigation of the capabilities a CAD system can offer to the management of construction projects. The work was undertaken in the UK construction industry. The main findings of Atkin et al (1986) were:

- CAD systems in the UK are mainly confined to the production of detailed drawings;
- most systems are used as 2-D drafting tools which are not suitable to incorporate non-graphical construction data;
- 3D systems are the most suitable for integrated applications with the necessity for separate databases;
- design practices should be modified to adopt component based approach; and
- the computer technology is available now to develop new approaches to the management of construction using CAD systems.

COMANDS (The Construction Management Display System)

The COMANDS system was developed by Stone and Webster in the USA for an integrated plant model (Zabitski and Hall 1989). In this system, the capabilities of 3-D solids computer model is combined with the efficiency of a computerized cost and schedule database to plan and schedule the construction process. To use the COMANDS system, the planner should disassemble the model created during design into its base elements which are then assembled in the same sequence as they would be built on site. Activities are then associated with these elements. Quantities and durations generated within the system are also related to these design elements. The COMANDS system can be considered as a comprehensive, advanced and useful CAD based construction management system. However, this system was developed for an integrated plant model and this could be of limited use to building and civil engineering projects. The same approach can, however, still be used to develop integrated systems for construction projects.

Builder

Builder was developed at MIT by Cheneff (Logcher and Sriram 1990). This system incorporates two sorts of databases, one is used for drawing creation and manipulation, and the other for construction scheduling. The Builder model can be seen as a serious attempt to generate construction schedules from drawings. Its key characteristics is the object oriented environment used to develop this system. This environment has facilitated the storage of physical objects such as doors, windows, walls, as well as generic tasks for their construction. The two knowledge bases of the Builder system are: Draw and Planner. Draw is a knowledge enhanced CAD system which was used for drawing creation, recognition and manipulation. Planner, on the other hand, was used as a scheduling tool. Its knowledge of construction sequences, estimating data and procedures to produce the project network are combined to develop the construction plan. The main criticism of the Builder model is its crude bar chart output which is not suitable for site uses.

Timberline Software

In the USA, Timberline Software Corporation (1990) have developed a link, known as CAD integrator, between AutoCAD and their Precision estimating plus system. The CAD integrator performs take-off directly from AutoCAD electronic drawings. It then moves the information into Precision Plus, an estimating spreadsheet-based program. Once estimating has been done, information can also be tied directly to Primavera and Microsoft Scheduling products to give more precise job planning. The key features of the CAD integrators are:

- it automatically takes off 3-D dimensions from AutoCAD drawings;
- it allows for specifications transfer from the estimating database to AutoCAD drawings;
- when drawings are changed, estimates are automatically updated; and
- estimates can be inserted into AutoCAD drawings.

Even though this system seems to offer a new generation of computer assisted design and estimating software, Gilleard (1990) recommends that further review of this system should be undertaken.

Morad and Beliveau (CAD/CPM Interaction)

Morad and Beliveau (1989) at Virginia Tech, have developed a planning technique based on the idea of integrating CAD and construction planning systems such as Critical Path Method (CPM) in the presence of an expert system. In this model, the construction process is simulated on a graphics display of a super workstation. The system operates by extracting information from the 3D computer model. The execution sequence is then generated using the extracted data and the knowledge rules of the expert system. The generated sequence is used to visually simulate the construction process using the Walkthru simulation package. This model can be seen as a serious attempt to integrate computer aided design and planning applications within a single system. However, the practicality and costs of such models should be assessed as they involve the coupling of CAD, simulation, expert system, databases and planning techniques on a relatively costly piece of hardware.

OARPLAN

Raymond Levitt at Stanford University has developed the Object-Action-Resource planning system (OARPLAN). This is a knowledge-based system that generates a list of required activities and their precedence constraints for a construction project from a reasoned analysis of objects, actions and resources. As part of the planning process, OARPLAN accesses design details either from a CAD system or a database (Levitt, Kartam 1990).

Aouad and Price (integrated planning system)

Aouad and Price (1993a, 1993b) developed a CAD-based planning system at Loughborough University in the UK. The system automates the planning of modular in-situ concrete structures by the coupling of two commercially available packages, namely AutoCAD 10 and Artemis 2000. Network plans are generated automatically using AutoCAD. These plans are transferred to the Artemis system for time and cost analysis. At present, the system can only handle activities associated with in-situ concrete design elements, i.e. concreting, steel fixing and form work operations. However, the open architecture of the system allows for further enhancements.

Conclusions

This paper reviews various models which are used in construction planning. The planning models which have been reviewed, include a selection of traditional and computer models developed during the course of this century. The review provides up-to-date information on construction management in general, and on construction planning in particular.

The traditional methods reviewed include: bar charts, network and line of balance techniques. Table 1, lists a selection of traditional methods and their application areas. These methods have existed for many years and have proven their worth. They enable proper planning and scheduling, as well as effective project control. Modern advances in computer technology have made the use of traditional methods easier. Nevertheless, Bar chart and CPM are the most popular planning, scheduling and controlling techniques used by UK and USA contractors. Though traditional methods make excellent use of the data generated by the planning process, they, however, suffer from the inability to manipulate the knowledge used by experts in generating plans. The need by researchers and practitioners to overcome this

fundamental limitation, has been one of the driving forces behind numerous attempts to research and develop AI based planning systems.

Model Name	Application
Bar charts	used to prepare schedules or to present schedules prepared using other means.
Linked bar charts	same as bar chart, except that linked bar chart provide a representation of the relationship between project tasks depicted on the chart.
CPM	used to compute the critical path through a network diagram. CPM produces a CPM schedule, task times, task floats, etc.
PDM	used to analyse activity on node networks. Allows specification of complex relationships between tasks. Similar to CPM in all other aspects.
PERT	analyses activity on arrow networks, using three time estimates. PERT works out the probability of completing projects at specified times.
GERT	used to produce construction plans in situations where uncertainty concerning future work exists.
Line of balance	used to plan projects which involve the construction of repetitive units.
Linear scheduling method (LSM)	used to plan linear projects such as pipe lines, roads, etc.

Table 1: Traditional models and their application areas

The review considers computer models, under three main categories: expert systems, simulation techniques and CAD-based construction planning models. These models have been developed, mostly in the USA, with a view to automating the construction planning process. Even though these planning models, which make use of state of the art information technology, demonstrate great effectiveness for facilitating construction project planning and/or control, only a few of them are being used by the industry. The lack of extensive commercial use of such systems by the construction industry, may be attributed to:

- the huge amounts of data input required by computer models;
- the lack of flexibility, within the systems, needed by construction planners to account for the unique nature of construction projects, and extra costs and staff training involved in using computer models.

Construction industry practitioners evaluate planning systems/models. The evaluation process assists them in selecting the appropriate systems for specific tasks and/or projects. When evaluating a planning method for use on a particular project, a number of factors, e.g. the extent to which the model meets project requirements and/or constraints, cost of software, training and maintenance, etc., could be considered. System application(s)/advantages and limitations, are two important factors that researchers and practitioners should use to evaluate planning models. Tables 2 and 3, outline these two factors, for a selection of planning systems/models reviewed in this paper. Thus, the tables provide, for the reader, a useful summary and evaluation tool of these planning systems/models.

SYSTEM / SYSTEM AUTHOR(S)	MAIN APPLICATION(S) ADVANTAGE(S)	MAIN LIMITATION(S)
Expert Systems		
Planex	can assist in the selection appropriate construction technology can generate activity networks can be used to produce activity duration, cost estimation and schedules. can be used to plan modular high rise buildings	supports only precedence relations.
Ghost	can generate network diagrams provide planning schedules	resources are not considered cannot determine activity duration
MIRCI	used to generate construction activities from design proposals can be used to produce schedules integrates expert systems, project management systems and database management systems.	still under development
CONSAS	can analyze construction schedules supports integration of various technologies	can be expensive due to the integration.
FEPP	can determine work activities can generate schedules	lacks CAD capabilities.
Time	produces construction activities based on type, function and location of work	lacks object-oriented capability needed to describe building components.
Simulation Models		
SIREN	simulates the construction of repetitive structures	lacks rules for generating the sequence of work inflexible
PRODUF	simulates a project and provides a forecast of the probabilistic project completion time	does not run on personal computers
Stochastic Network Model for Planning Scheduling	simulates a project and produces a set of decision criteria which demonstrate possible variations in outcomes	requires a considerable amount of time

Table 2: Expert Systems and Simulation Models - applications/advantages and limitations

SYSTEM / SYSTEM AUTHOR(S)	MAIN APPLICATION(S) / ADVANTAGE(S)	MAIN LIMITATION(S)
Retik, Warszawski and Banai(1990)	assists in construction scheduling provides graphic representation of schedules and structures	deals with only one aspect of construction planning
Builder	generates construction schedules from drawings supports an object-orientated environment supports integration	bar char output of Builder is not suitable for site use
Morad and Beliveau (CAD/CPM Interaction)	simulates the construction process and generates project execution sequence	expensive
OARPLAN	analyses project objects, actions and resources to generate activities and their precedence	it is only a developmental expert system
Aouad and price (Integrated planning system)	automates the planning of modular in-situ concrete structures can generate network plans	can only handle limited activities

Table 3: Integrated & Computer Graphics Models - applications/advantages and limitations

A number of the systems reviewed here are operational prototypes. The full potential of such systems has not been fully realized by the construction industry. It is therefore, imperative that researchers and developers of current generation of integrated planning models, work very closely with the industry. This will help ensure that systems, developed by research institutions, will have a better than average opportunity to be adopted by the industry. Furthermore, collaboration between researchers and practitioners, would promote the realization that reaping the benefits of good construction planning, afforded by effective information management, will only be brought about by the development of more appropriate and realistic computer models, capable of being adopted by the construction industry. These models, would then greatly contribute to the goal of achieving more effective construction project planning and control.

A number of systems, which have been recently developed or which are currently under construction and/or investigation (including some of the systems reviewed in this paper), which have modules that deal with construction planning, have adopted the integrated approach. One of the primary goals of integrated systems, is to enable different participants in a construction project to represent project information, deal with issues pertaining to various phases of a construction project and exchange information using the same environment. The environment itself may use a combination of various relevant systems. Examples of such systems include, Simultaneous Prototyping Applications for Construction Environment (SPACE) (Alshawi, M. 1996) and Open System for Construction (OSCON) at Salford University (Tracy, A., Child, T., Aouad, G., Brandon, P. and Rezgini, Y. 1996). The main

limitations of most construction systems that adopt the integrated approach, are firstly, their heavy reliance on a multitude of proprietary software systems; secondly, the probable high cost of the systems and maintenance. However, after careful examination of a large selection of various planning models, including those that adopt an integration approach, and in light of ever improving computer hardware and software performance and ever decreasing prices, and in light of the numerous advantages of integrated construction systems, we have formed the view that an integrated approach to construction planning, is the best way forward. Furthermore, the limitations, currently inherent in integrated systems, can be greatly reduced by incorporating into the systems, as many non proprietary software modules, specifically designed to meet system requirements, as possible. The non proprietary modules, do not have to be part of the system at its inception, they could instead, be developed and introduced into the system after its successful prototyping.

Finally, this paper gives up-to-date information on construction planning. It provides a quick reference on construction planning. Researchers and practitioners investigating construction planning models, with a view to developing more realistic and appropriate models, would find the information, provided in this review, very useful.

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