Computers & Structures Vol. 40, No. 1, pp. 67–74, 1991
Printed in Great Britain.

0045-7949/91 $3.00 + 0.00

A CONCEPTUAL MODEL FOR CLAIM MANAGEMENT IN CONSTRUCTION: AN AI APPROACH

N. Riad, D. Arditi and J. Mohammadi
Department of Civil Engineering, Illinois Institute of Technology, Chicago, IL 60616, U.S.A.

Abstract—Delays are the major cause of construction disputes. Among the several dispute resolution methods, mediation has been an effective solution. The one problem which can be attributed to all dispute resolution methods is the lack of a preventive approach and the lack of a systematic and comprehensive technical evaluation of the entire problem. Given the magnitude of the problem there seem to be distinct advantages in developing a Knowledge-Based Expert System (KBES) for time-based claim management. The domain of knowledge of the KBES presented in this paper will be directed towards analyzing disputes that arise due to different types of delays (excusable/compensable, excusable/noncompensable, nonexcusable; independent, concurrent, serial) and determining the responsibility of each party. It will utilize a procedure called 'Time Impact Analysis' and involves the use of network-based scheduling tools to identify, quantify, and explain the cause of a schedule variance. The various modules that make up the KBES for an integrated claim management process have been clearly identified. Specific methods have been developed to perform time impact analysis and to apportion damages in different delay/acceleration situations.

INTRODUCTION

Disputes in the construction industry divert resources from meeting project objectives and consequently increase costs. Construction firms, property developers, public agencies and owners suffer reputation problems when disputes mark the headlines of the news media.

Delays are the major causes of construction disputes. The word 'delay', as used here, is a relative term in construction. It means the time overrun either beyond the contract date or beyond the date that the parties agreed upon for delivery of the project [1]. In terms of financial considerations, delay-related claims are big money items in the field of litigated construction matters [2]. To the owner, delay can mean loss of revenue through lack of production facilities and rentable space, or a continuing dependence on present facilities. To the public owner, it means that a building or a facility is not available for use as planned. The service revenues lost through delays can never be recovered. To the contractor, delay means higher overhead costs because of the longer construction period, higher material costs through inflation, and escalation costs due to wage increases. Additionally, the contractor's working capital is tied up so that other projects cannot be pursued.

In the past, delays in the completion of construction projects used to be a mutually accepted condition. Even courts often recognized delays as normal occurrences in the construction process. Today, with tight budgets on the part of the owners, who usually want to expend only to the limit of the assigned budget, and the extra cost of staying on the job longer than planned, delay becomes a real cost item. As a result, delays often end up in disputes.

Among the several dispute resolution methods, 'mediation' has been an effective solution in dealing with disputes because it makes use of an experienced impartial and knowledgeable person with the construction process. As described later, there are also several other methods available. Each method has its drawbacks and may involve a complicated and lengthy process. One effective method of handling disputes with an existing method is through automation and artificial intelligence. Given the magnitude of a dispute problem, there seem to be distinct advantages in developing a Knowledge-Based Expert System (KBES) for time-based claims management.

Considerable work has already been undertaken by Arditi and Patel [3–5] to conceptualize the problem and develop a preliminary model. The various modules that make up the proposed KBES for an integrated claims management process have been clearly identified. Specific methods have been developed to perform time analysis and to apportion damages in different delay/acceleration situations.

The objective of this paper is to describe a Knowledge-Based Expert System (KBES) for time-based claims management that not only can make a human mediator's job more effective and economical, but that can also reduce the occurrence of disputes considerably. Indeed, the system will be available to all parties at all times; a party who is planning a change in the project will be able to observe the expected consequences (in terms of the parties' responsibilities with respect to time and money) by running the planned action through the system before the change is initiated.

The paper contains a description of time-based disputes and the alternatives for their resolution. The advantages of building a KBES for claims management, the domain of knowledge for the proposed KBES, and the development of a KBES for claims management are also presented and discussed.

TIME-BASED DISPUTES AND THEIR RESOLUTION

As the cost of individual projects increases dramatically, the costs of delay seem to increase at an even greater rate. For instance, Consumer's Power Company of Michigan estimates that its 1300 megawatt nuclear power plant that was under construction near Midland, Michigan had cost almost 50% more to complete ($1.5 billion rather than the original estimate of less than $1 billion), due principally to the costs of a two-year construction delay. The delay was the result of funding problems and design changes, and the cost increase is ascribed principally to inflation. Consumer's Power had previously filed suit for $300 million or more for delay damages due to costs involved in start-up delays for another nuclear power plant. Delay costs included loss of revenues. Another example is the joint venture for the Grand Coulee third power plant that suffered losses due to delays on a $112.5 million fixed price contract. They are claiming a delay cost of the order of $30 million to $35 million. Finally, a joint venture of contractors on the Oroville Dam in California sued the state for $15 million for delays resulting in extra costs during excavation. The joint venture contractors claimed that the rock did not react in the expected manner, and they incurred additional costs that should be paid by the state. The state, in turn, was countersuing. In its countersuit was a claim for almost $2 million in compensatory damages because the job was completed in 48 months rather than the contractual 40 months [1].

Not only are the extra costs resulting from delay large, but they also represent substantial percentages of overall contract values. The simplest, most economical and fastest method of settling claims if *negotiation*. In this process, the two parties involved discuss the problem and try to compromise on the claim. This method is usually adopted when the claim does not affect project cost and duration by a large amount.

Whenever direct negotiation between the parties fail, the dispute is litigated or resolved by means of an alternate dispute resolution method like arbitration, mediation, or the use of Dispute Review Boards.

Litigation at courts of law is the method used by public owners whereas private owners prefer the alternate methods. At courts of law, juries decide the outcome based on witness opinions and expert testimonials. The decisions are subject to appeal at higher courts.

When the dispute cannot be resolved by negotiation, the parties can attempt *arbitration*. Arbitration is a consentual forum; it must be entered into by mutual agreement of the parties. In arbitration, hearings are conducted not quite as formally as in a court of law but in a business-like manner by competent and impartial arbitrators selected by the parties from a list provided by the American Arbitration Association (AAA).

Arbitration has several advantages over litigation [6]. Claimants, in construction delays, often prefer the arbitration forum as expert analysis, speed, simplicity, and privacy often work to the claimant's advantage. Arbitrators, unlike judges, are often familiar with the realities of the construction industry, and they are more interested and empathetic with the complexities of analyzing delays. Moreover, it is a relatively inexpensive method of resolving claims. The hearings are private and are arranged to the convenience of the parties and undesired public exposure is avoided. There are no strict rules of evidence, presentation of records, documents, pictures, opinions and testimony of witness. And finally, the award is final and binding. The main disadvantage of arbitration is that a party may be deprived of his right to explain his case before a jury, and moreover owners of construction projects often assert that arbitration is an unfavorable forum for their interests, especially in delay claims. It may be that owners' institutional interests are not well represented on lists of potential arbitrators. Designers, contractors, and attorneys comprise the bulk of the AAA's national panel of arbitrators, and none of these professions' interests align wholeheartedly with owners. It may be that public owners prefer taxpayer jurors to decide their fate [7].

Mediation is a relatively recent development. It is nothing but negotiation plus a broker. Mediation consists of the effort of an individual to assist the parties in reaching a settlement by direct negotiation between themselves [8]. The mediator, selected by the parties from a list provided by AAA, participates impartially in the negotiation, advising and consulting the various parties involved. The mediator cannot impose a settlement, but can only seek to guide the parties to the achievement of their own settlement. The Construction Industry Mediation Rules have received the full endorsement of the National Construction Industry Arbitration Committee (NCIAC).

Mediation begins when the parties to the dispute submit a one-page summary of their positions plus pertinent contract documents to the mediator. Then, over a 2–3 day period, the mediator meets briefly with both parties together and separately. During these meetings, the mediator tells each party about the weakness of its own case without revealing anything about the other party's position.

Apart from being a faster, cheaper, and less complex way of resolving disputes than litigation and arbitration, mediation maintains and strengthens the relation between the two parties [6, 9]. It is more acceptable to the parties since its decision is not binding [7]. The parties involved may accept or reject mediation and go to arbitration or to a court of law. The cost of mediation is shared by both parties. Either party can withdraw at any time. There is no record of the mediation proceedings. The proceedings, if unsuccessful, cannot be used in future arbitration or litigation.

A new method being developed by a committee of the American Society of Civil Engineers, Underground Technology Research Council (UTRC), recommends that contractors' bid documents be placed in escrow, the owners share more of the risk associated with unforeseen cost increases, and use is made of a *Dispute Review Board* [10]. The Dispute Review Board is composed of three members. One is selected by the owner, one by the contractor, and the third one is selected by both. The board members are sent weekly progress reports. They visit the project periodically and are aware of the progress of the job and the development of actual conditions. The findings and recommendations of the Dispute Review Board are not legally binding [11]. The selection of impartial and qualified board members is essential for the success of this method. A disadvantage is that the project must be large enough to justify the relatively higher cost.

Each method possesses its own problems. *The one problem which can be attributed to all of them is the lack of a preventive approach to the resolution of claims.* Before the dispute can be settled, a comprehensive technical investigation is needed for the analysis of the overall operation. Specifically, the following questions must be analyzed and properly answered:

What went wrong?
What would have been the outcome if a series of measures had been taken?
What was the solution in projects with similar dispute problems?
What type of resolving technique would best fit the dispute?
Are the cost and time spent on a specific settling technique justified?

Most of these analyses can effectively be performed using a powerful KBES. Such a system must be able to perform technical evaluations, predict the outcome of a project upon changes in the project and of course it should be able to continuously update its knowledge base as new cases are introduced to it. Moreover, the existence of a KBES for claims management will, in most cases, be a way for avoiding disputes. In addition, it can be used as a complement for the mediator or the arbitrator or for the jury in a court of law.

ADVANTAGES OF BUILDING A KBES FOR CLAIMS MANAGEMENT

"Machines that lack knowledge seem doomed to perform intellectually trivial tasks. Those that embody knowledge and apply it skillfully seem capable of equaling or surpassing the best performance of human experts" [12].

Most complicated problems do not have tractable algorithmic solutions since many important tasks originate in complex social or physical contexts, which generally resist precise description and rigorous analysis. Human experts achieve outstanding performance because they are knowledgeable. If computer programs embody and use this knowledge, then they too should attain high levels of performance, and this has proved to be true repeatedly in the short history of expert systems.

Knowledge is a scarce resource whose refinement and reproduction creates wealth. Traditionally the transmission of knowledge from human expert to trainee has required years of education and internship. Extracting knowledge from humans and putting it in computable forms can greatly reduce the costs of knowledge reproduction and exploitation.

In delay claims analysis, the judgement on a problem is generated partly by schedule analyses, but is based on a mediator's judgement. The mediator's expertise is a combination of dealing with past cases and his good knowledge of technology and law.

The advantages of such a system can be summarized as follows.

The system can store a large volume of data in its data base unit and can handle and/or analyze the data in a short time.
The system can offer a more cost-effective solution to dispute resolution than existing methods mentioned in the preceding section.
The user can consult the KBES privately after a dispute has occurred. The user can also consult the KBES before the dispute occurs for 'What If' analyses. This guarantees the confidentiality of the information presented. The opinion of an expert is always there whenever needed.
The system will act in a neutral way and will never be in favor of one of the parties involved in a dispute, except through the data presented, as a human mediator might be.
The system will help field personnel quickly grasp the facts and implications of a proposed modification to the contract [13], and know their legal rights.
The KBES will always keep expanding by adding to the knowledge base, using the knowledge of its users, and therefore gaining more experience with time [14].
With a KBES, disputes are expected to be resolved in a much shorter time.
The system will provide an inexpensive method for transferring knowledge and legal expertise to construction practitioners [13].

DOMAIN OF KNOWLEDGE FOR KBES

The idea of developing a KBES for claims analysis and capturing the expert knowledge of the law is not new. Lester's 'Lawyer on a Microchip' can be used in identifying various entitlement issues [15]. Cobb and Diekmann [13] developed a KBES that analyzes disputes related to differing site conditions. Other researchers [16–19] have elaborated on how this can be achieved. There are also expert systems that were developed to solve scheduling related problems. De La Garza and Ibbs developed an expert system for the analysis and evaluation of construction scheduling networks from an owner's perspective [20]. Hendrickson *et al.* developed an expert system that involves the choice of construction technology, the definition of work tasks, the estimation of required resources and duration and costs, and the preparation of project schedules [21]. McGartland and Hendrickson discussed the various if-then rules, and the aim and organization of a system to monitor construction progress [22]. In the schedule analysis and control system proposed by Avots, the system would have to draw on the same judgemental and experimental knowledge that is used by cost and schedule engineers and project managers [23].

The domain of knowledge of the KBES described in this paper is directed towards analyzing disputes that arise due to different types of delays and determining the responsibility of each party. It makes use of scheduling techniques and legal principles.

According to the general conditions of contract issued by the American Institute of Architects (AIA), classic delays occur when a period of uselessness and/or idleness is imposed upon the construction work. Such delays are classified as follows:

Excusable/compensable

These delays are not caused by the contractor. Furthermore, the contractor is entitled to a time extension and damage compensation for extra costs associated with the delay. Typically, these are owner-caused delays. Delays caused by owners can include, but are not limited to [1, 24]:

failure to provide access, property, or right-of-way;
failure to fund the project on time;
owner-furnished materials not available;
stop order for reasons including safety;
introduction of major changes in requirements;
failure to make progress payments; and
interference by other prime contractors working for this owner.

The owner is also subject to the consequences of acts by his designated representative, including the architect/engineer and/or the construction manager. These delay causes can include, but are not limited to [1]:

defects in the plans and the specifications;
unreasonable delays in review of shop drawings or approval of material;
improper or delayed change orders;
orders to stop work;
direction to accomplish the work in a certain manner;
failure to coordinate between prime contractors;
inadequate information;
inadequate supervision; and
failure to provide temporary heat (if contractually provided).

Excusable/non-compensable

These are delays for which neither the contractor nor the owner is at fault. The contractor would be entitled to a time extension but no delay-type damage compensations. Clause 5 of the standard federal contract states that the contractor will not be assessed liquidated damages by reason of delays "due to unforeseen causes beyond the control and without the fault and negligence of the contractor." These causes of delays include, but are not limited to [1, 24]:

acts of God;
acts of the public enemy;
acts of the government (sovereign or contractual);
acts of another contractor in performance of a government contract;
fires;
quarantine restrictions;
strikes;
freight embargoes; and
delays of subcontractors or suppliers due to similar causes.

Non-excusable

These delays are caused by the contractor which may entitle the owner to be liquidated or other damages. These causes of delays include, but are not limited to [1, 24]:

slow to mobilize;
failure to man the project;
failure to provide sufficient equipment;
poor workmanship;
failure to coordinate;
inadequate supervision;
unforeseen accidents;
cash flow limitations;
bid shopping; and
poor planning.

Depending on the timing of the events, delays can further be classified at the activity level as follows:

Independent delays

An independent delay is one that occurs independently of any other delay and that has no effect on any other activity in the project. It is relatively easy to identify, to establish its effect on total project duration, and to allocate cost burdens to the parties involved.

Concurrent delays

Concurrent delays occur when there are two or more independent delays during the same time period. It is difficult to apportion damages if the concurrent delays consist of delays attributable to both the owner and the contractor [7].

Serial delays

In this type of delay the action of one of the parties can cause a series of delays in a number of succeeding activities.

GENERAL STRUCTURE OF KBES

The main reason for initiating a consultation session with the KBES is the need to know how one can apportion delay-dollars between the contractor and the owner. This is especially true if the contractor needs to accelerate the project by a number of days due to delays caused by either party.

An iconic representation of the KBES is shown in Fig. 1. The expert system shell contains three major parts, the *inference engine* that makes use of the rules stored in the *knowledge base* to infer conclusions and the *LISP program* which is used for manipulating files and interfacing with the scheduling software package through batch processing. Before the consultation starts, the user should have generated as-planned, as-built and as-projected schedule files in ASCII format by using a scheduling software package. This is normally done in any project on a routine basis.

The KBES described in this paper will utilize the Critical Path Method technique using a leading project management software package to reconstruct past events. This procedure is called 'Time Impact Analysis' and involves the use of network-based scheduling tools to identify, quantify, and explain the cause of a schedule variance. Time impact analysis is normally undertaken to either support or defend against a delay claim in a litigation, arbitration or mediation proceeding. It can be referred to as 'Forensic Scheduling'. Time impact analysis can be characterized as a comparative analysis which utilizes several scheduling documents generated by the system. The *as-planned schedule* is the original work schedule prepared by the contractor at the inception of the work. It reflects the contractor's planned approach to pursue the work. The *as-built schedule* presents the actual sequence of events which occurred during the course of the project. It contains all the delays and accelerations that took place up to the point in time when the analysis is done. A series of *adjusted schedules* are prepared to explain the sequence of events which transform the 'as-planned schedule' into the 'as-built schedule', thus explaining the major schedule variances which occurred during the course of a project. Once all the work changes and delays are considered and an 'as-built schedule' is prepared, the project completion date has to be known. If the project is complete, the project completion date is the one shown on the 'as-built schedule'. If the project is not complete, the 'as-built schedule' has to be combined with the remaining activities of the project in the 'as-planned schedule' in order to get an *as-projected schedule* which will show the expected project completion date. The responsibility for each delay is assigned by using the contract documents, the chronological delay information collected during the course of the project, and accepted industry practices as a guide. Based on this information, an *owner-accountable schedule* is prepared. It identifies the project delay caused by the owner.

A flow chart that shows a general sequence of events is shown in Fig. 2. The sequence of events proceeds by asking the user for basic project data such as name, size, type of contract, etc. The user will have to specify the number of days by which the project is to be accelerated. Whether the project is completed or in progress is determined during this interchange. If the project has been completed, the analysis will identify the liabilities and apportion the damages in the traditional way. If the project is in progress, the system will identify the liabilities, as before, and will perform an analysis that will apportion the delay-dollars between the two parties.

In the first interface the LISP program will read the three files, supplied by the user's scheduling package, analyze them, and create a chronological list of the activities that were delayed/accelerated and/or added/cancelled.

Starting from the second interface the KBES will loop through the list generated and pick the listed activities in chronological order then create the adjusted schedules through interfacing with the scheduling software package. Liability on the current activity will then be assigned, by the inference engine, through an interactive session of questions and answers with the user. In the third interface a compression analysis will be performed on the remaining activities by an amount equal to the delay duration of the current investigated activity.

At the final stage of the consultation the expert system will calculate the dollar amounts assumed by each party and then generate a report with all its conclusions.

After reviewing recent surveys of commercially available expert system shells [17, 25–27] and con-

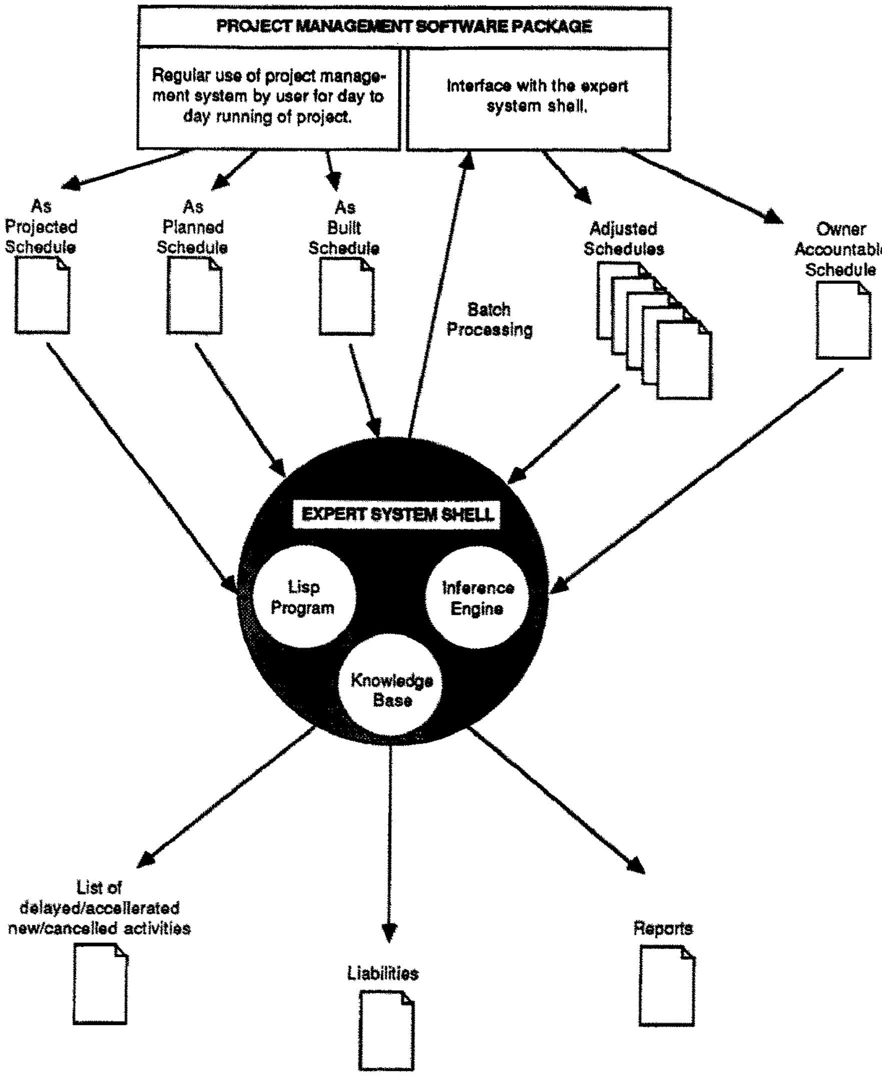

Fig. 1. Structure of KBES.

ducting one for the purpose of this study [28], it was decided to select Personal Consultant Plus, developed by Texas Instruments. The decision was made because of two main reasons: the first was that the shell was a rule-based system and rules are well suited for representing legal knowledge.

Rules are data structures that resemble 'if-then' statements used in conventional programming. The 'if' part of a rule consists of a set of conditions; when the conditions are satisfied, facts contained in the 'then'/conclusions part of the rule may be inferred, and actions specified in the 'then' part performed. Because rules are actually data structures, they can be created and deleted fairly independently of one another. This is a major advantage that will help in expanding the system continously.

The second reason was the program's wide variety of features, such as *frames* which help in breaking down the knowledge base into small manageable modules that are easy to debug, *meta-rules*, and other functions such as the DOBEFORE and CONSIDERRULE functions, for controlling the inference process within a part (or all) of the knowledge base and allowing the developer to specify which rule(s) should be tried first before trying the current rule, *active values* that watch a specific parameter(s) and perform actions specified by the developer whenever the value of these parameters are assigned a new value, the ability to *mix* between backward and forward chained rules thus gaining more inferencing control, a built-in *LISP* (Scheme) environment which offers more power and more control to the developer, the ability to *interact* with dBaseIII which will allow storing different claims cases, and its capability of running other programs from within it written in C, Pascal and FORTRAN. This latter capability is especially important to the KBES because at some point during the consultation process the expert system will need to interact with a scheduling package to analyze a construction network by transferring information back and forth.

A set of LISP programs to perform the interfaces mentioned in Fig. 2, and a prototype of a knowledge base, have been developed by the writers as a hierarchical fault tree of claims. Each node of the tree is represented as a frame where the root frame of the tree is time-based claims (top event) and the branches (causative events) of the tree are the different causes for delays. The consultation proceeds from the top event in the direction of a branch causative event according to the user's answers. Liability will be assigned after the system reaches the last event. The knowledge within the system was extracted through legal documents and will be further enhanced through interviews with experts. The system is implemented in a modular way that will facilitate maintaining it in the future.

CONCLUSION

Several methods for settling claims are described in this paper. Construction owners and contractors are, however, disenchanted by these methods' shortcomings and have been experimenting with alternate dispute resolution methods that are faster, more

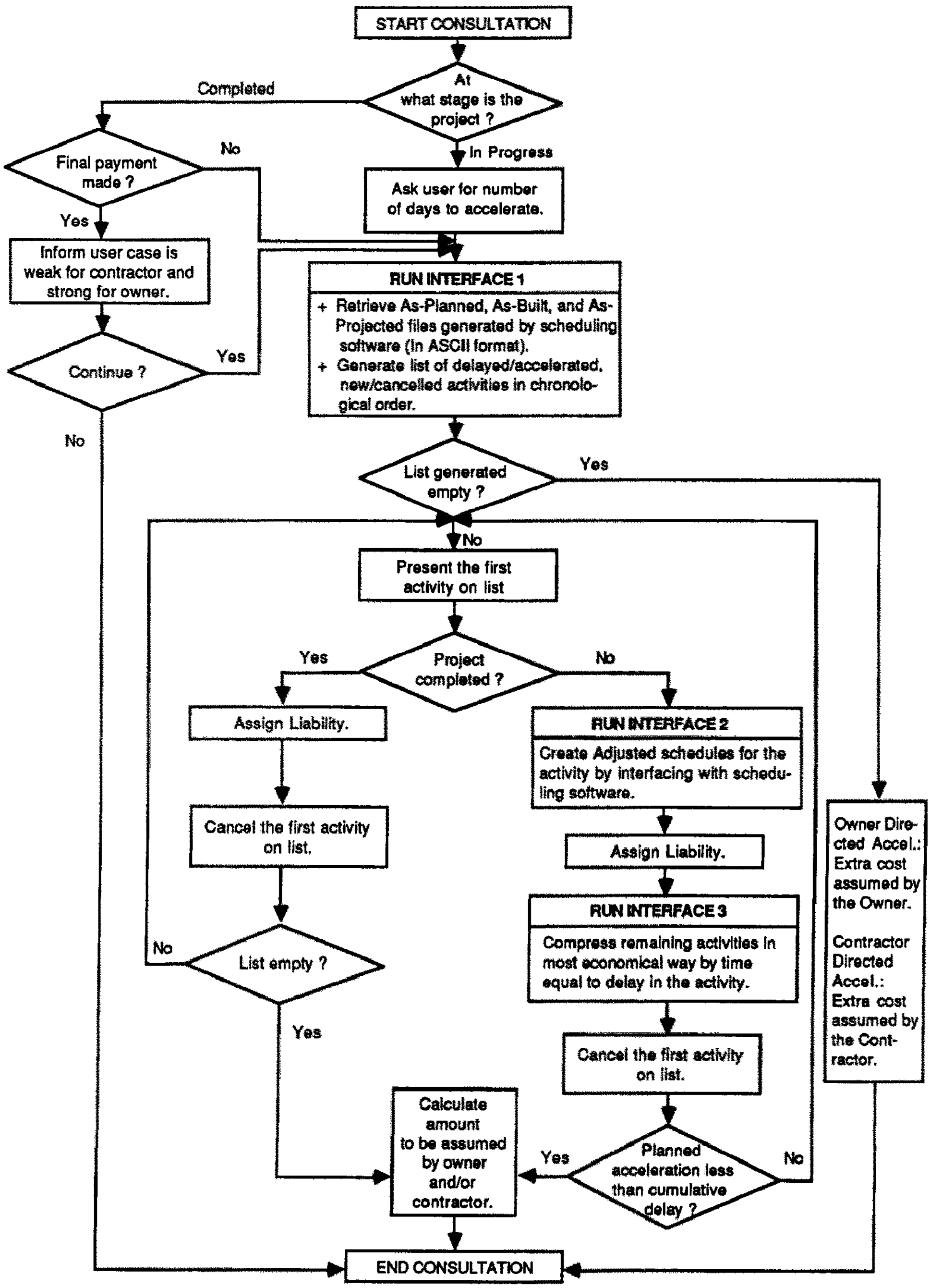

Fig. 2. General sequence of user/machine interactive session.

economical, impartial, convenient, and private. They would like to be able to test the consequences of planned modifications to the contract and measure the probabilities of these modifications that could generate costly disputes. They would also like to be aware at the planning phase of probable situations that could cause delays that might end up in disputes. The expert system concept presented in this paper has been developed as a response to these needs. It makes use of time impact analyses that are performed on the expert system's command by scheduling software normally used by construction companies/owners in managing their projects. It also makes use of a knowledge base loaded by the developers with legal information in the form of if-then rules. The inference engine combines data received from time impact analyses and from the legal knowledge base to infer conclusions.

When completed, the system will be consulted by negotiators, arbitrators, and mediators to facilitate their decision-making process. It could also be used by contractors and owners independently to test the consequences of planned changes in the contract before initiating the damages. Another potential application of this KBES is for planning a construction project. The system can be used before the actual conduct of a construction project to foresee possibilities for delays that might end up in disputes. Thus specific planning and strategic decision-making may be performed to avoid a potential delay or at least to be prepared for smoother settlement and resolution. Work to include this feature in the KBES is in progress.

REFERENCES

1. J. J. O'Brien, *Construction Delays*. Cahners Books International, Boston, MA (1976).
2. C. Carter and Silverman, *Construction Litigation: Representing the Contractor*. John Wiley, New York (1986).
3. B. K. Patel, Expert systems in forensic scheduling. Thesis presented at Illinois Institute of Technology in partial fulfillment for the requirements of the degree of M.S. (1988).
4. D. Arditi and B. K. Patel, Expert systems in claims management. *Int. J. Project Management* (accepted for publication).
5. D. Arditi and B. K. Patel, Impact analysis of owner-directed acceleration. *J. Construct. Engng Management, ASCE* **115**, 144–160 (1989).
6. W. R. Quernes, How to prevent and prepare for schedule-related construction contract dispute. Thesis presented to Ohio State University in partial fulfillment of the requirements for degree of M.S. (1983).
7. B. B. Bramble, *Construction Delay Claims*. John Wiley, New York (1987).
8. American Arbitration Association, *Construction Contract Disputes: How They May Be Resolved*. AAA, New York.
9. D. D. Meisel and W. M. Stein, Mediation the possible resolution of 'Impossible' situations. *Construction Specifier* **35**, No. 6, 22–25 (1982).
10. Hope for tunneling disputes, *Engng News Record* **219**, No. 18, 14 (1987).
11. Underground Technology Research Council, *Avoiding and Resolving Disputes in Underground Construction*. A Draft Report by the Technical Committee on Contracting Practices (1987).
12. F. Hayes-Roth, D. A. Waterman and D. B. Lenat, *Building Expert Systems*. Addison-Wesley, Reading, MA (Jan 1983).
13. J. E. Cobb and J. E. Diekmann, A claims analysis expert system. *Project Management J.* **17**, No. 2, 39–48 (1986).
14. R. D. Logcher, Adding knowledge based systems technology to project control systems. *Project Controls: Needs and Solutions*. ASCE, New York (1987).
15. J. Lester, Lawyers on a microchip. *Civil Engng, ASCE* **57**, No. 6, 68–69 (1987).
16. J. Diekmann and T. Kruppenbacher, Claims analysis and legal reasoning. *J. Construct. Engng Management, ASCE* **110**, 391–408 (1984).
17. M. Maher (Ed.), *Expert Systems for Civil Engineers: Technology and Application*. ASCE, New York (1987).
18. C. Kostem and M. Maher (Eds), *Expert Systems in Civil Engineering*. ASCE, New York (1986).
19. Z. Kraiem and J. Diekmann, Representing construction contract legal knowledge. *J. Comput. Civil Engng, ASCE* **2**, 202–211 (1988).
20. J. De La Garza and W. Ibbs, A knowledge engineering approach to the analysis and evaluation of schedules for mid-rise construction. *Construction Research Series No. 23*, University of Illinois at Urbana (1988).
21. C. Hendrickson, C. Zozaya-Gorostiza, D. Rehak, E. Baracco-Miller and P. Lim, Expert system for construction planning. *J. Comput. Civil Engng, ASCE* **1**, 253–269 (1987).
22. M. McGartland and C. Hendrickson, Expert system for construction project monitoring. *J. Construct. Engng Management, ASCE* **111**, 393–407 (1985).
23. I. Avots, Application of expert systems concepts to schedule control. *Project Management J., PMI* **16**, 51–55 (1985).
24. T. A. Poulin, Avoiding contract disputes. *Proc. Symp. sponsored by the Construction Division of ASCE* (1985).
25. P. Ludvigsen, W. Grenney and D. Dyreson, Expert system tools for civil engineering applications. In *Expert Systems in Civil Engineering* (Edited by C. Kostem and M. Maher), pp. 18–29. ASCE, New York (1986).
26. L. Press, Eight-product wrap-up: PC shells. *AI Expert* **3**, No. 9, 61–65 (1988).
27. Report on Expert System Shells for Construction Industry Application, Loughborough University of Technology, Loughborough, U.K. (1985).
28. D. Arditi and N. Riad, Selection of an expert system shell for a computerized mediator—a knowledge based expert system for claims management. Report submitted to the State of Illinois Technology Commercialization Center (1988).