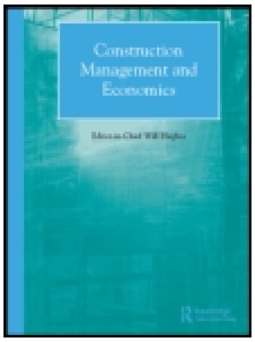

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Computer aided construction delay analysis and claims preparation

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Computer aided construction delay analysis and claims preparation

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Delays are the most common and costly problem encountered on construction projects. Analysing construction delays has become an integral part of the project's construction life. To prepare for litigation, schedule documentation proving responsibility must be prepared. With present methods of tracking projects, the preparation of such schedules can be time consuming and costly. The analysis itself is usually complex and can be aided by a computerized approach. This paper describes the introduction of a computer system for delays claim analysis called computerized delay claims analysis (CDCA). The system utilizes the isolated delay type (IDT) technique. Part of this system can use existing software such as project management, cost control, database management and spreadsheets. In addition to these, an expert system tailored to the specific expertise of construction claims has been used to facilitate the decision making process. CDCA is tested against a real case study of a building project to demonstrate its effectiveness in determining the responsibility of contracting parties with respect to the project's delays. The system is expected to assist in improving the process of delays analysis, thus reducing the cost of claims preparation.

Keywords Delays, claims, expert systems, computing, planning, project control.

Introduction

Delays on a construction site are normally inevitable and, as a result, many claims arise with few of them ending up in litigation. Present methods of preparing claims analyses for litigation are time consuming and costly. A large portion of effort in preparing these claims arises from the meticulous digging through piles of project documentation to sort and ascertain pertinent delays encountered during the project. The process is usually quite difficult and expensive due to the lack of available documentation. In an attempt to overcome this problem and improve the process of claims analysis due to construction delays, this paper describes the introduction of a computer system for delays claim analysis called computerized delay claims analysis (CDCA). The system is a result of ongoing research work carried out to identify the problematic areas of the delay analysis and claim preparation procedures currently used in construction.

The proposed system utilizes the isolated delay type (IDT) technique (Mazerolle and Alkass, 1993; Mazerolle, 1993). It also uses a database management system of stored and organized project information. This can reduce the cost and time associated with claims preparation. It is comprised of integrated existing management software tools and is designed to accommodate four major components, namely the user, project management, database management and an expert system.

The user's role is the gathering and input of project activity data, which provides the as-planned schedule, as well as the tracking of the project once construction starts. The project management component involves the use of project management software which is capable of importing and exporting project information to and from external database or spreadsheet software. The database management or the spreadsheet software component is needed for manipulation of project data recorded by the user. The expert system component is tailored to the specific expertise of construction delays to facilitate the decision making process of delay assessment.

CDCA uses the export/import capabilities of project management software, as well as the data manipulation capabilities from the database applications. It is designed to provide two key functions: the first being project control, and the second, claims analysis capabilities. In this context, project control is limited to the traditional planning, scheduling, and tracking of projects. Claims analysis, including delay analysis, refers to the manipulation of the tracked project data to determine responsibilities for project delays.

CDCA requires that from the start of the project, data are exported from the project management software into a format which can be edited by a database software. If delays are encountered, the cause and classification of the delay type, be it excusable compensable, excusable noncompensable or nonexcusable, are assessed using the expert system and documented immediately. Once the project data have been updated, they are imported back into the project management software and an adjusted schedule is generated. The system updates project data, assesses delays and documents delay information as it happens. Thereby, in the event of a claims analysis, a major part of the data gathering is already done, thus reducing the cost of claims preparation, since almost 70% of the time spent on preparing a claim is utilized on searching and organizing information and the remaining 30% of the time is spent on analysing that claim.

In the preparation of the claims analysis, the system database contains historical project data and delay information, which was documented from the project control phase. This information can be easily retrieved and prepared in a manner suitable for the claims analysis. The information is then imported into the project management software where claims analysis schedules can be produced.

When preparing a claim, delay analysis techniques are used to determine the effect of delaying events on the project's completion date. The main issues in ensuring the accuracy of a delay analysis are: proper classification of delay types, concurrent delays, and real time CPM analysis.

Construction delays

The literature (Kraiem and Diekmann, 1987; Reams, 1989, 1990; Alkass and Harris, 1991; Alkass *et al.*, 1993; Wickwire *et al.*, 1991; Mazerolle and Alkass, 1993) generally classifies delays according to liability into two major types, namely excusable or nonexcusable delays. Excusable delays can be further classified into compensable and noncompensable delays.

Excusable compensable delays are caused by the owner's actions or inactions. When contractors encounter this type of delay, they are entitled to a time extension as well as monetary compensation. An example of an excusable compensable delay would be when an owner denies access to the site once the notice to proceed is given.

Excusable noncompensable delays are delays where neither the owner nor the contractor is deemed responsible. When this type of delay is encountered, only a time extension will be warranted since there are no grounds for damages. Some examples of excusable noncompensable delays are unprovoked strikes, or any 'Act of God'.

Nonexcusable delays are delays which result from the contractor's or its sub-contractor's actions or inactions. Consequently, this type of delay presents no entitlement to a time extension or delay damages for the contractor. The owner, however, could be entitled to delay damages. An example of a nonexcusable delay would be when a contractor fails to provide sufficient manpower to complete the job on time.

Concurrent delays refer to delay situations when two or more delays (regardless of type) occur at the same time, or overlap to some degree; either of which, had the delays occurred alone, would have affected the ultimate completion date. Normally, any concurrent delay which involves an excusable delay results in a time extension. When compensable and nonexcusable delays are concurrent, a time extension can be issued or the delay can be apportioned between the owner and the contractor.

Delay analysis techniques

Different techniques are currently used by practitioners in the construction industry to analyse delays. The following is a list of the delay analysis techniques (Leary and Bramble, 1988; Reams, 1990; Revay, 1990, 1991; Alkass and Harris, 1991; Wickwire *et al.*, 1991; Alkass *et al.*, 1993; Mazerolle, 1993).

1. Global impact technique
2. Net impact technique
3. Adjusted as-built CPM technique
4. 'But for' or collapsing technique
5. Snapshot technique
6. Time impact technique
7. Isolated delay type

For a detailed assessment of these techniques the reader is referred to Alkass *et al.* (1993), Mazerolle and Alkass (1993) and Mazerolle (1993).

There are three main concerns for ensuring the accuracy of a delay analysis, which are:

1. Delay type classification (excusable compensable, excusable noncompensable, and nonexcusable) –

this ensures that wrongful entitlement does not occur;
2. Concurrent delays – this can have an effect on the overstatement of compensation; and
3. Real time analysis – this ensures that when delays are incorporated in the delay analysis, the CPM that was in effect at the time of delay is used.

None of the existing delay analysis techniques except for the isolated delay type (IDT) consider all three issues at the same time. Therefore, the IDT technique has been used for delay analysis within the CDCA.

The proposed computer system

In an attempt to improve the process of claims analysis due to construction delays, a computer-based system (CDCA) within an integrated environment was proposed. By facilitating the delay analysis process, the time and cost of claims preparation can be reduced. The system is designed to assist management teams (the owner's or the contractor's) involved in construction projects, with the analysis of claims arising from delays. It consists of integrated existing management software tools, including project management, databases, spreadsheets, word processors and an expert system. Figure 1 shows a graphical representation of the integration of the proposed system.

In practice, when a contractor or an owner seeks compensation due to project delays a third party, normally a claim consultant is approached. Part of the procedure is to produce documentation that will stand up in court to show that the other party is responsible for the delay to the project's completion date. One of the problems associated with conducting a claims analysis is the meticulous digging through piles of project documentation to sort and ascertain pertinent delay information. Therefore, an automated method to perform this process would be highly desirable and cost effective. Part of this work involves this specific task. However, in performing claim analysis the following factors (Mazerolle, 1993; McCullough, 1989) need to be addressed:

1. Contract documents language;
2. Overall delay of all impacts;
3. Start date of the impact;
4. End date of the impact;
5. Delay for each responsible party;
6. Timing of delays;
7. Concurrent delays;
8. Float ownership;
9. Drop in productivity;
10. Standby time;
11. Revised activity duration;
12. Improper constraints or logic; and
13. Revised constraints or logic.

The source of this information is project documentation such as contract documents, letters, minutes of meetings, notes, material receipts, supervision and inspection reports, resource data and costs, daily reports, extra work orders, occurrence reports and cost reports of a project, and so on. Unfortunately, the varied and often ad hoc sources of this information present the claims analyst with a difficult task in preparing an accurate entitlement schedule. This task alone can take several months, and can end up costing the client large sums of money in consulting fees. For this reason, a database management system has been integrated within the CDCA to store information on each delay when it occurs – information such as delay type, description of the delay, who is responsible, delay code number, date of occurrence, letters and notes sent and received including dates, resources used and their costs, and so on. The advantage of keeping track of this information when the delays occur becomes evident when delay information is required, and can be easily retrieved. To improve the process further, an expert system linked to CDCA is designed to assist in ascertaining the type of delay in question, as well as indicate which party is liable, and what actions should be taken.

As is shown in Figure 1, the system involves four major components, the user, project management, database management and an expert system.

The user's role is to gather and input project data, which provides the as-planned schedule, as well as track the project once construction starts. This enables status reports and schedules to be generated, including delay information pertinent to future delay analyses.

The project management component involves the use of a project management software (for the purpose of this work, the Primavera Project Planner was utilized) which is capable of importing and exporting project information to and from the external database.

The database management component is needed for the manipulation of project data recorded by the user. Programs such as spreadsheets or databases are best suited for this type of work. In this format, information on the construction delays (such as types, duration, comments, approvals, responsibilities, and so on) is stored and easily sorted in a manner appropriate for claims analysis. For the purpose of this work, Lotus 123 has been utilized.

The expert system component involves the use of a system called the delay advisor (Alkass *et al.*, 1987; Alkass and Harris, 1991; Tribaldos, 1994), capable of advising on construction delays to facilitate the decision making process. The expert system contains extensive knowledge on different types of scenario that might be encountered on construction sites. Through a series of questions, the expert system can zero-in on the classification of a delay, be it excusable compensable, excusable noncompensable or nonexcusable. In addition to classification, the expert system can give comments as to what procedures should be taken to minimize the effect of the delay as well as what legal course, if any, should be pursued. Any information that is generated by the expert system is exported to the database in order to be included in the comment section of the exported project data.

The system assesses delays and incorporates delay information as it occurs. Thereby, in the event of a claims analysis, a major part of the data gathering is already done.

The expert system (delay advisor)

Expert systems and their various applications in construction have been extensively described in the litera-

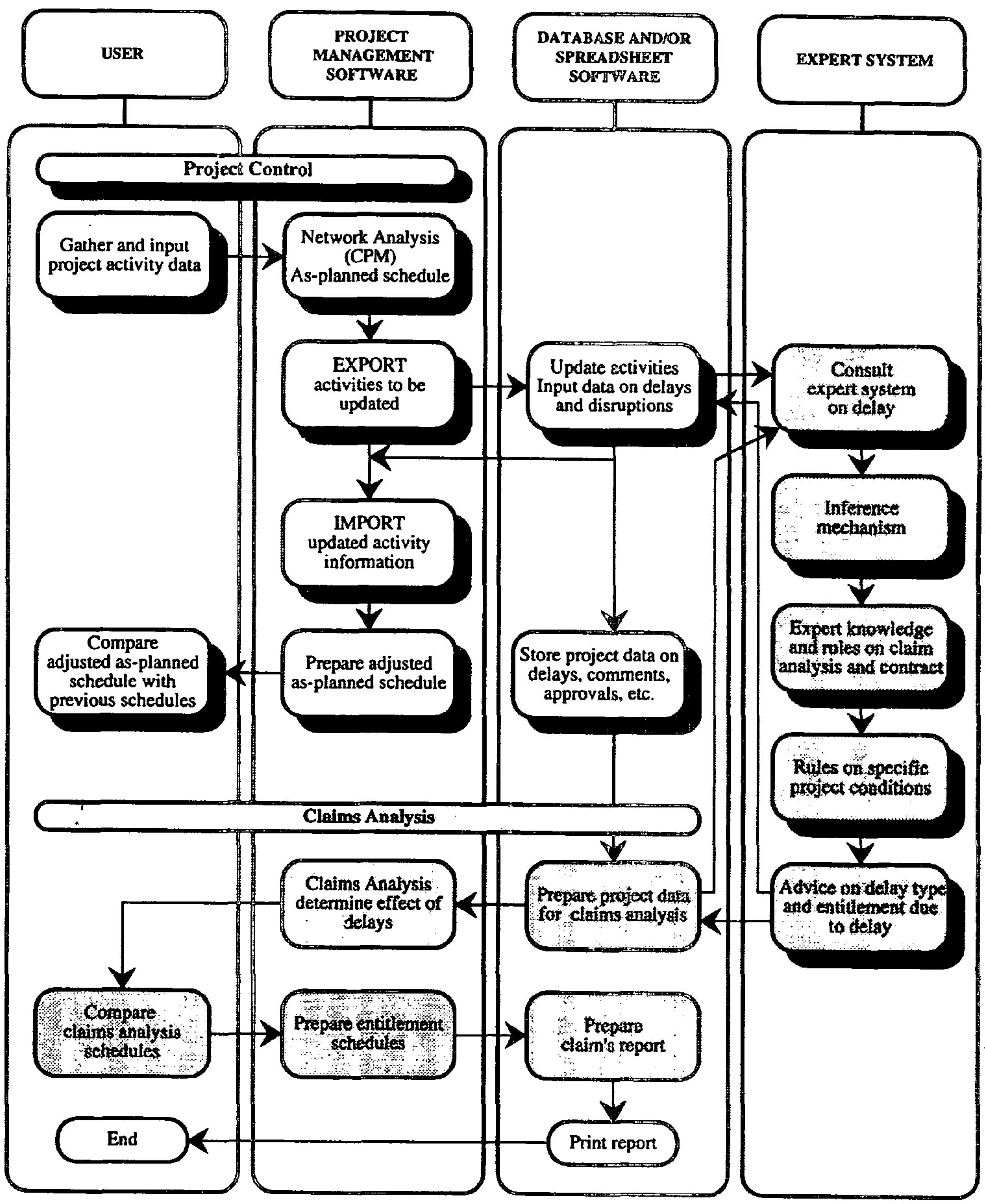

Figure 1 CDCA integration flowchart (claim analysis and project control; claim analysis; project control)

ture (Mohan, 1990). They have been used for claim analysis (Deikman and Kruppenbacher, 1984; Cobbi and Deikman, 1986; Alkass *et al.*, 1987; Bubbers and Christian, 1992). The delay advisor is an example of an expert system which could be incorporated into the CDCA system at any stage, when various potential entitlement issues from given facts are identified. It provides guidelines for preparing the documentation and procedures necessary to pursue the case. A likely prediction of the outcome is also presented (entitlement or not, excusable compensable, excusable noncompensable or nonexcusable delays) together with an explanation of the reasoning.

The mode of the operation consists of a series of questions linked by (IF_THEN) logic, the decision tree being a set of rules arranged to reflect the reasoning of the expert practitioner.

The knowledge for the delay advisor was extracted from the literature (Abrahamson, 1975; Lyn and Jones, 1979; Wickwire *et al.*, 1991) and extensive interviews with practitioners in the field of construction claims. Six practitioners were interviewed during a period of four months. The knowledge was also reviewed by a lawyer experienced in the area of construction claims. Finally the working model was viewed and criticized by the experts and modified accordingly.

Figure 2 shows a computer screen printout of the delay advisor main menu. Figure 3 illustrates a logic tree for the unforeseeable ground conditions.

The consultation begins by the user providing responses to the questions in the form of multi-choice menu of YES, NO or DO NOT KNOW. The applicable rules are located and further questions posed, ultimately leading to a particular decision or course of action to solve the problem in hand. Figure 4 shows a screen printout of a consultation session with the delay advisor.

Other aspects , conditions or contract clauses are dealt with in a similar manner, however, the rules governing the decision process are written to deal with the domain of expertise. At any stage in this process, the user can call for explanations and the path of reasoning adopted. Furthermore, guidance on standard information, record-keeping, cost estimate preparation, and so on, needed for presentation of the case may be requested. A facility of this kind was found very helpful for training users relatively inexperienced in presenting the appropriate claims documentation.

CDCA integration process

Referring to Figure 1, CDCA is designed to provide two key functions: the first being project control and the second, claims analysis capabilities. In this context, project control is limited to the traditional planning, scheduling, and tracking of construction projects. Claims analysis, including delay analysis, refers to the manipulation of the tracked project data to determine the responsibilities of the project's delays.

Project control

This function can be split up into two categories; first, setting up the as-planned schedule and second, tracking and updating the project's progress. Figure 1 highlights the pertinent items on the system's flowchart which deal with the project control aspect.

Setting up the as-planned schedule can be a lengthy exercise depending on the size of the project and the level of detail required in the schedule. This procedure usually involves several people: the owner, the project manager, managers or knowledgeable persons of the various disciplines concerned, and planner(s)/scheduler(s). Through group discussions the project objectives, work packages and areas of concern are outlined. From these, activities are identified, realistic duration and logical inter-relationships are applied, thus creating an as-planned schedule which can be followed to achieve the realization of the project to the satisfaction of all parties.

The second aspect of project control is tracking and updating the project. Through progress reports and on-site visits, the status of the project can be determined and the schedule updated. The frequency of updates depends on the level of control the project manager or owner would like to achieve. A copy of the schedule prior to updating should be maintained for comparison purposes. If a major delaying event occurs between update periods, an interim update should be performed.

Once project activities have been tracked, the as-planned schedule can be updated. The conventional method would be to access the project management package, duplicate the as-planned project data (for target comparison), and update the project data. CDCA requires that all activities affected by the update be selected and exported from the project management software into a format which can be read by either a database software (dbase), spreadsheet software (Lotus 123, Excel) or ASCII type application (such as an editor). Most project management software with import/export capabilities have these options; users can use whichever format they are comfortable with.

The following is the step-by-step procedure to be used in the project control phase of the proposed system every time the schedule is to be updated:

1. Select activities: identify all the activities to be updated from the project management software. To narrow down all the activities into a list of potential activities to be updated, the following selection criteria are recommended:

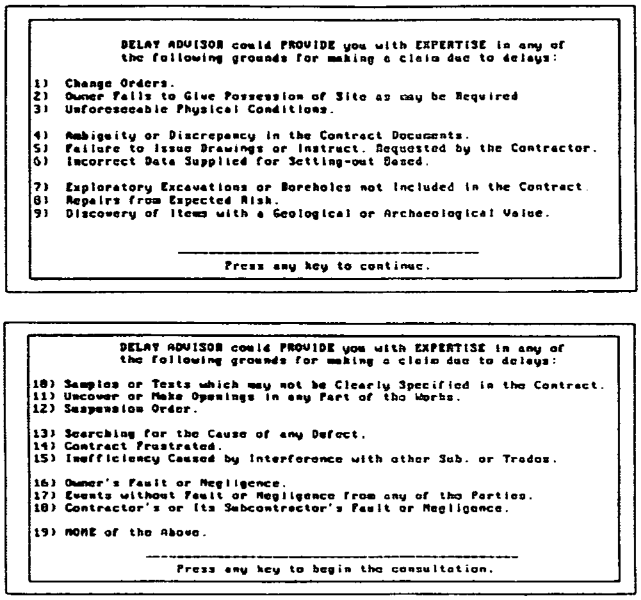

Figure 2 The delay advisor main menu

   i. all activities that have started but are not yet completed,
   ii. all activities that have an early start or early finish scheduled before the actual date.
2. Export and update: once the appropriate project data are selected, export the activities to a database to be updated. In the event of the project experiencing delays, classifying the type of delay as soon as possible is very important, while it is still fresh in the minds of the project personnel. This could be done by a project manager or with the assistance of the expert system. All too often, as time passes, details of the delay or disruption fade away leaving the time consuming and costly task of searching through old documentation for clues. An important feature of the project management software is its capability to include free format comments. This becomes valuable and necessary in the documentation of delays, disruptions, delay types, responsibilities, or any comments which will clarify matters.
3. Import: once the exported project data have been updated with pertinent comments dealing with any delays that may have occurred, the file can now be imported back into the project management software. New relationships are respected and incorporated in the project update. It is recommended that a copy of the database update be kept for use in future claims analysis, if required.
4. Recalculate: once the updated project data are imported, recalculation of the schedule will yield an adjusted as-planned schedule. Comparing the adjusted as-planned completion date of the latest updated schedule and the completion date of the schedule prior to updating quantifies the effects of delays that occurred during that update period. Comparing the latest updated completion date with the as-planned completion date gives an indication of how far behind or ahead the project is. It is up to the project manager to react to any negative indications and steer the project back on course.
5. Repeat steps 1 to 4 for each required schedule update.

Once steps 1 to 4 have been completed, there exists an as-planned schedule, an as-built schedule, and several (as many as were required) interim schedules which captures the project's progress. The most important item that has been captured, with respect to the proposed systems, is the detailed and up-to-date information on delays and delaying events that occurred during the project's life, including the classification of delay type.

The CDCA system can be used by owners or contractors who wish to perform a cursory on-going delay analysis of the project. As the project tracking data are prepared, a delay schedule can also be developed by using the same tracking information, but eliminating delays from the activity data which are the responsibility of the other party, similar to the 'but for' technique. When the schedule is updated, the difference in project completion dates between the tracked project schedule and the delay schedule will indicate the amount of delay caused by the other party. Looking at it from the owner's point of view, the owner would keep all excusable noncompensable and excusable compensable delays in the schedule. From the contractor's point of view, the contractor would keep all excusable noncompensable and nonexcusable delays in his/her schedule.

Claims analysis

Presently, when claims analysis is required, historical project documentation is dug up and time is spent meticulously searching for information related to the project delays. Further time is spent determining the cause, type and responsibility of the delay. The proposed system assesses delays and incorporates delay information as it happens. The main advantage is in the fact that an up-to-date, comprehensive list of delays, responsibilities, dates and actions/inactions exists. There is no need to gather and sift through mounds of project documentation to piece together an account of events.

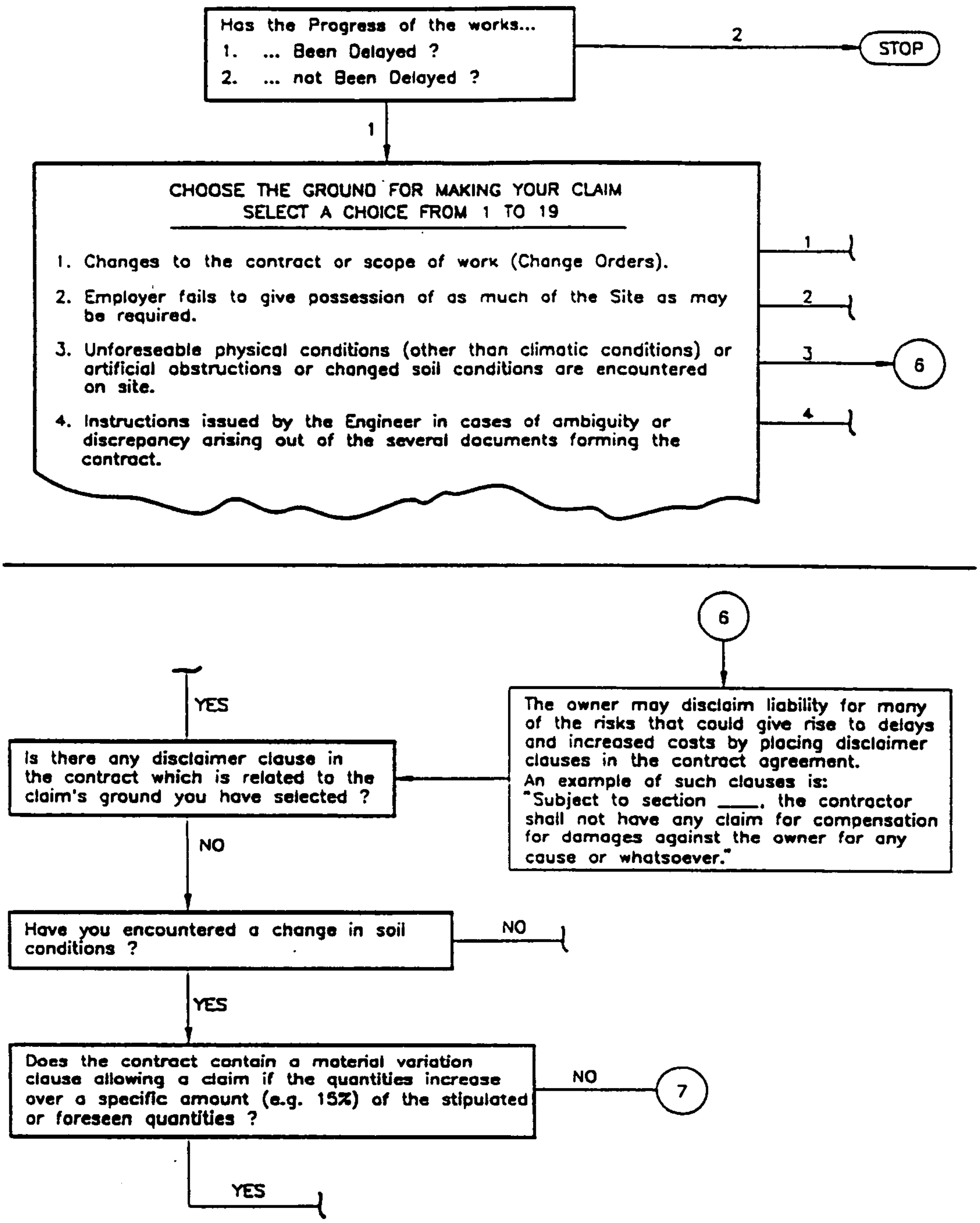

Figure 3 The decision tree for the unforeseen ground conditions

Thereby, in the event of a claims analysis, a major part of the data gathering is already done. This alone can reduce the cost and time associated with claims analyses. Figure 1 highlights the pertinent items on the system's flowchart which deals with the claims analysis aspect.

The system utilizes the isolated delay type technique, which uses the systematic and objective approach of the time impact and snapshot techniques, while applying the scrutinizing approach of the 'but for' technique. This delay analysis technique takes into account the proper classification of delay types (excusable compensable, excusable noncompensable and nonexcusable), concurrent delays and real time analysis.

The first step in performing a claims analysis would be to gather all pertinent delay information and sort it in a manner which will support the claim. This is done quickly by referencing the database files containing the updated project activity data from the project control (tracking) phase, or simply exporting all project data from the as-built schedule. The sort capabilities of the

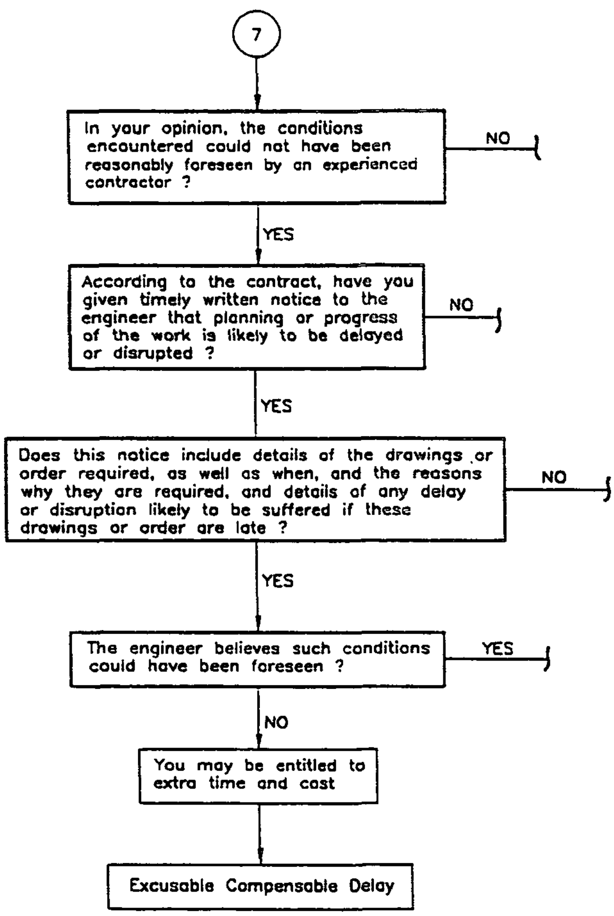

Figure 3 The decision tree (*continued*)

database software enable the project activity information to be sorted chronologically to separate activities into their respective time periods. Further sorting will group activities based on the type of delay, which was coded with the help of the expert system in the early stages of the project tracking. Assessing the causes and classifying the type of a delay is complex, requiring careful judgement executed by very experienced practitioners. Further consultation with the expert system is still possible at this stage if additional clarification or advice is required. In addition to the classification of delay types, the expert system can give comments as to what legal course, if any, should be pursued. Any information that is generated by the expert system should be included in the comment section of the project data, to maintain an up-to-date database.

In preparing a claims analysis, two schedules have to be produced: a delay analysis schedule and a claims analysis schedule. The delay analysis schedule is needed for two reasons: first to assess project overrun (time), and second to ensure that the proper Critical Path Method (CPM) is used in the next analysis. Claims analysis schedules are needed to assess the delay that is compensable. Regardless of who is performing the analysis, the claims schedule excludes any delays classified as excusable noncompensable (EN) since excusable noncompensable delays such as unprovoked strikes only warrant time extensions, not damages. Excusable noncompensable (EN) delays have no bearing on the extension of project completion dates, with respect to claims analysis. This can be seen in Figure 5 which shows a comparison between tracking, delay analysis and claims analysis schedules. Note that the critical path of the delay analysis schedule is different from that of the claims analysis schedule. In this example the variance is small, but it can lead to significant variations if excusable noncompensable delays are included throughout the project. It is important to note, however, that when using the isolated delay type technique, the schedule must include excusable noncompensable delays before progressing to the next time period. This ensures that the delayed activities have proper duration, hence the correct critical path will be generated. Also, the relationships amongst activities must be verified to ensure that the next analysis is using the appropriate CPM schedule.

When using the isolated delay type technique, several time periods are chosen based on the delays encountered. The number of time periods depends on how detailed a claim analysis is required. Once the project activity data are sorted into the appropriate time periods and categorized by delay type, schedules can be created for the delay analysis. Comparing the schedule prior to adding the delays, and then after the delays are included, quantifies the effect of the delay(s) during that time period on the project completion date.

The mechanics of creating the delay analysis schedules from the database file are no more difficult than selecting all pertinent activity and delay data from the database, and then importing them back into the project management software. Once the information is imported, delay schedules can be produced.

The following is the step-by-step procedure to be used in the claims analysis phase of the proposed integrated system, to create delay analysis schedules once the database has been sorted chronologically, and time periods have been chosen:

1. Select activities within the time period: identify all the activities and delaying events in the database that fall within the time period in question. Create a file containing the selected activities.
2. Import: once the appropriate time period activities and delaying events are selected, import the file into the project management software. Maintain a copy of the previous project management schedule file so that target comparisons can be performed.
3. Recalculate and update: once the database project data are imported, updating the schedule will yield

```
The Progress of the Works Has :

 Been Delayed ◄             Not Been Delayed
```

```
              CHOOSE THE GROUNDS FOR MAKING YOUR CLAIM.
                    (Select a choice from 1 to 19)
              -----------------------------------------
                      Press any key to continue.

1. Changes to the contract or scope of work (Change Orders) :

 Yes                        No ◄

2. Owner fails to give possession of as much of the site as may be
   required :

 Yes                        No ◄

3. Unforeseeable physical conditions (other than climatic conditions) or
   artificial obstructions or changed soil conditions are encountered on
   site :
 Yes ◄                      No
```

```
        The Owner may disclaim liability for many of the risks
        that could give rise to delays and increased costs by
        placing disclaimer clauses in the contract agreement.
        An example of such a clause is :

        '' Subject to Section ---, the Contractor shall not
           have any claim for compensation for damages against
           the Owner for any stoppage or delay from any cause
           whatsoever. ''

              -----------------------------------------

                       Press any key to continue.

Is there any disclaimer clause in the contract which is related to
the claim's ground you have selected ?

 Yes                        No ◄
```

```
Have you encountered a change in soil conditions ?

 Yes ◄                      No
```

Figure 4 Screen printout of a consultation with the delay advisor

an adjusted project completion date. Comparing this adjusted completion date with the project completion date of the previous schedule quantifies the effect of the chosen delays that occurred during that time period. Comparing the latest adjusted completion date with the as-planned completion date quantifies the total amount of time the project has over-run to date given the chosen delays.

4. Adjust activity duration and relationships: once the delay to the project has been assessed for the time period, any changes to activity duration, relationships and/or constraints which were adopted during the project for that time period must be incorporated into the adjusted schedule. Equally important is that the adjusted schedule include excusable noncompensable (EN) delays regardless of who is performing the analysis. Addressing these two issues ensures that the proper CPM is in effect when progressing to the next analysis.
5. Repeat steps 1 to 4 for each time period chosen, starting with previous adjusted schedule.

Once steps 1 to 4 have been completed for all the time periods chosen, the total amount of delay to the project can be determined by summing up all the individual delay amounts established from each delay analysis.

If it is the owner who is performing the delay analysis, then only the delayed activities which have nonexcusable (NE) and excusable noncompensable (EN) delays are selected. On the other hand, if it is the contractor who is performing the delay analysis, then delayed activities which include excusable compensable (EC) and excusable noncompensable (EN) delays are selected. If the amount of time eligible for compensation is of interest

```
Does the contract contain a material variation clause allowing a claim
if the quantities increase over a specific amount (e.g. 15%) of the
stipulated or foreseen quantities ?

 Yes                       No ◄

In your opinion, could the conditions encountered have been reasonably
foreseen by an experienced contractor ?

 Yes                       No ◄

Have the conditions encountered, which are outside the control of the
contractor, produced a change in the work schedule ?

 Yes ◄                     No
```

```
Does the engineer believe such conditions could have been foreseen ?

 Yes ◄                     No

After checking your documents (details of the drawings, defined methodology,
specifications, and other contract documents), can you challenge the
engineer's position and prove that he is wrong or can you get an expert
capable of doing it ?

 Yes ◄                     No
```

```
      The contractor is entitled to CLAIM for EXTRA TIME and MONEY

                    EXCUSABLE COMPENSABLE DELAY
```

Figure 4 Screen printout of a consultation with the delay advisor (*continued*)

(claims analysis), then excusable noncompensable (EN) delays are not included in the analysis.

It is important to make sure that the activity duration and relationships are correct prior to performing each delay analysis. If this is neglected, delaying events may be tied to incorrect critical paths, and may yield erroneous delay analysis results.

It is important to note that the reason many time periods are used is to ensure that the respective CPM is used at the time the delay(s) are applied in the delay analysis.

As a result of the five steps outlined, a contractor preparing a delay analysis (including EC and EN delays) or a claim analysis (including EC delays only) will have schedules which quantify and support his/her claim. Similarly, an owner is able to produce schedules which would support his/her claim, based on either a delay analysis (including NE and EN delays) or a claim analysis (including NE delays only).

System validation

The importance of system validation has been discussed in the literature [Geissman and Schultz, 1988; Finlay *et al.*, 1988; Satre and Massey, 1991). The best way to validate the effectiveness of CDCA would be to use it on an on-going project, keeping track of the project and delays as they occur. Upon completion of the project, a delay analysis could then be performed using the collected project and delay information. Since at this stage this is a time consuming process, a historical project that has had a claims analysis already performed was used as a case study. The project data from this case study were used to re-enact the tracking of the project. By updating the project at regular intervals, any delays encountered were recorded in the appropriate updates. Once the project tracking was completed, a delay analysis using the project tracking information was made. The scope of the case study was limited to determining the effect of delays on the project in time only, not cost. Therefore, the delay analysis taken from the contractor's point of view determined how much time the contractor was justifiably overrun on the project.

The project used for this case study was selected based on the following requirements:

1. experienced delays;
2. had a claims analysis already performed; and
3. had delay information reasonably well laid out.

Case study

The project selected was the construction of a 15-storey residential tower. The contractual duration was 52 weeks at a cost of $8 366 000. The project was to start on 8 August 1989, and have the majority of work completed by 7 August 1990 (one year later). During the course of the project several delays were encountered, resulting in a total elapsed project duration of 90 weeks. As a result, the contractor filed a lawsuit for compensation for losses due to the project overrun. The project consisted of 84 activities broken up into six major areas: structural, mechanical, electrical, exterior brick and windows, elevators, and miscellaneous finishes.

For the purpose of the case study, documentation from the project was used to re-enact the tracking of the project. The delay information used in this case study was well defined but some delaying events lacked specific dates and links to activities. In cases where specific dates or links were unclear, the delaying events were associated with activities on the critical path, since the claims report had identified them as being delays which affected the project's completion date.

Regarding delays the project encountered, they were grouped into three categories:

1. owner's failure to provide unrestricted access to work areas;
2. change orders; and
3. other delays, as per the claims report.

Owner's failure to provide access to site resulted in 29 days of excusable compensable (EC) delays. A total of 26 change orders generated a total of 76 days of delays that were deemed excusable compensable, as per the claims

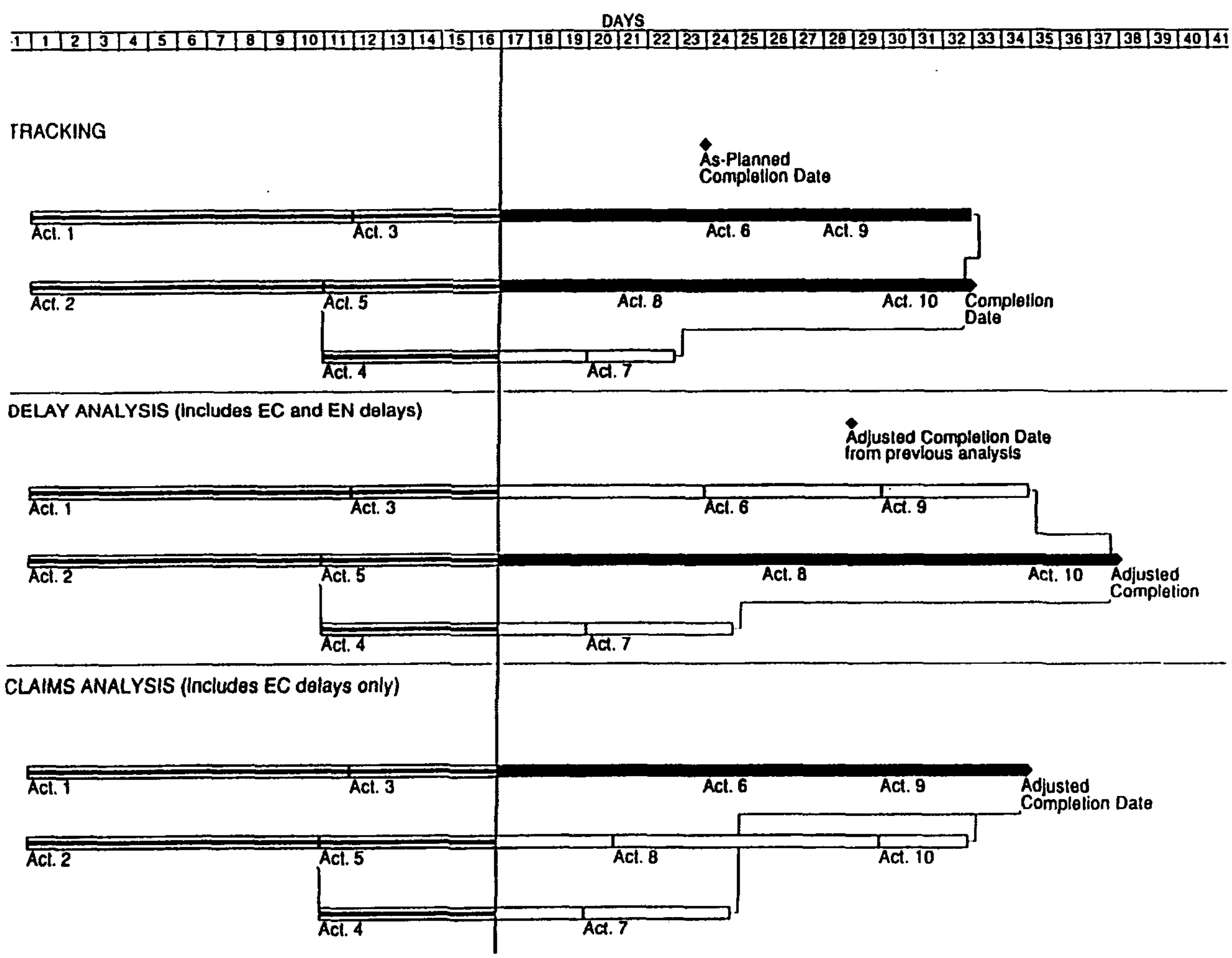

Figure 5 Comparison of tracking, delay analysis and claims analysis schedules

Table 1 Summary of delayed activities used in the case study

Activity	8 Aug 1989–30 Apr 1990	1 May 1990–31 Dec 1990	1 Jan 1991–19 Jul 1991
S00	8 days EC		
	21 days EC		
	4 days EC		
	5 days EC		
	4 days EN		
S01	4 days EC		
	2 days EN		
	4 days EN		
	3 days EN		
S02	9 days EC		
	8 days EC		
	3 days EN		
S03		28 days EC	
		14 days EN	
		3 days EN	
E03		18 days EC	
E04		43 days EC	
B01			30 days EC
E16			30 days EC
EL00			2 days EC
F02			7 days EN
F03			10 days EC
F04			20 days EC

report. Further delays to the completion of the work were experienced by the contractor. These delays are divided into the three basic categories; 135 days of excusable compensable (EC), 13 days of excusable noncompensable (EN) and 40 days of nonexcusable (NE). Since this case study involved an existing project with an existing claims report, the delays with their delay type (EC, EN, NE) were already defined. This was a good ground to test the delay advisor export system in determining delay types. The test revealed that the expert system managed to arrive at similar conclusions every time it was consulted.

The first step in performing the delay analysis was to gather all the project data and delay information that were documented in the project control phase of the case study. As a result of the application of the CDCA system, a concise list of delayed activities, delay types and miscellaneous information was made available. By getting a schedule report from Primavera of the as-built project, viewing and analysing the project data and delay information was very quick and easy. The as-built activities were sorted by time, generating a chronological listing of activities and delays.

Since the delay analysis was performed from the contractor's point of view, all delays which were nonexcusable (NE) were removed from the schedule. This was necessary since we were trying to determine the amount of time the contractor was justifiably delayed. Once the list of activities and delays was developed, an assessment of the delays, their magnitude and their occurrences shed light as to which time periods would be used to perform an effective delay analysis. Because each delay can potentially alter the project's critical path(s) it is advised that the more time periods used in a delay analysis, the more accurate the analysis will be. If the time period is too wide, the critical path(s) that exists at the time of the analysis could be quite different from that which originally existed. Thus, delays that were actually associated with critical activities might not be associated with a critical path in the analysis. Similarly, non-critical delays may be associated with a critical path during the analysis, giving over-exaggerated results. A decision as to the level of detail of an analysis must be addressed up front. To assess the effectiveness of the system, three time periods were used. These were: 8 August 1989 to 30 April 1990, 1 May 1990 to 31 December 1990 and 1 January 1991 to 19 July 1991. A summary of the delayed activities used in the case study are shown in Table 1.

In performing the first delay analysis, the as-planned schedule was used as the starting point. All activities were exported from the as-planned schedule in Primavera to Lotus 123. By referencing the chronological listing of the as-built delay information, delayed activities that fell within the 8 August 1989 to 30 April 1990 time period were determined as shown in Table 1. Once these delayed activities were established, the activities in the exported as-planned WK1 file that were not identified within the time period as being delayed, were

ACT	RD	TITLE	ES	EF	AS	AF	EC	EN
S00	76	Structure - Parking	08-Aug-89	22-Sep-89			Y	Y
				House not removed until 17Aug89 (8d EC)				
				Building permit late, issued 6Sep89 (21d EC)				
				Rain (4d EN)				
				Added length to form & pour work (4d EC)				
				Change orders 23, 33 => 5d EC				
S01	28	Structure - Ground Floor	25-Sep-89	13-Oct-89			Y	Y
				Downed crane (2d EN)				
				Rain (4d EN)				
				Heavy snow (Feb90 7,8,9,14,15,16) (3d EN)				
				Added length to form & pour work (4d EC)				
S02	37	Structure - 2nd Floor	16-Oct-89	03-Nov-89			Y	Y
				Heavy snow (Feb90 7,8,9,14,15,16) (3d EN)				
				Added length to form & pour work (9d EC)				
				Change orders 36, 37 => 8d EC				

Import file for first time period

ACT	RD	TITLE	ES	EF	AS	AF	EC	EN
S03	50	Structure - 3rd Floor	02-Mar-90	08-Mar-90			Y	Y
				Trucker strike (14d EN)				
				Rain (3d EN)				
				Wait for design change/clarifiations (28d EC)				
E03	24	Electrical - 3rd Floor	02-Mar-90	09-Mar-90			Y	
				Change orders 39,41,42,44,45,46,47 => 18d EC				
E04	51	Electrical - 4th Floor	12-Mar-90	21-Mar-90			Y	
				COs 52-55,57,62,63,66,67,70,76,66 => 43d EC				

Import file for second time period

ACT	RD	TITLE	ES	EF	AS	AF	EC	EN
B01	35	Ext. Brick & Windows - Ground Floor	19-Sep-90	25-Sep-90			Y	
				Additional window work (30d EC)				
E16	38	Electrical - Roof	13-Nov-90	22-Nov-90			Y	
				Design change - Electrical rough-in (30d EC)				
EL00	137	Elevators - All Floors	11-Sep-90	28-Mar-91			Y	
				Change orders 78,86,87 => 2d EC				
F02	72	Misc. Finishes - 2nd Floor	29-Aug-90	27-Nov-90				Y
				Abnormal weather-Topping over radient heat(7d EN)				
F03	75	Misc. Finishes - 3rd Floor	03-Sep-90	30-Nov-90			Y	
				Design change-Delay in deliv. of railing (10d EC)				
F04	85	Misc. Finishes - 4th Floor	06-Sep-90	05-Dec-90			Y	
				Design conflicts (20d EC)				

Import file for final time period

Figure 6 WK1 files imported for delay analysis removed from the file. From the listing of the as-built activities, the type of delay and its duration were then imposed on the WK1 file. Modifying the 'remaining duration' of the delayed activities and adding any relevant delay information produced a concise WK1 file that contained only delayed activities that were between 8 August 1989 and 30 April 1990.

Figure 6 shows the WK1 files for the three delay analyses that were imported back into Primavera. For the first delay analysis, the as-planned schedule that now contained revised project information was recalculated and an adjusted project completion date was generated. This adjusted completion date of 15 November 1990, compared against the as-planned completion date of 7 August 1990, indicated that excusable compensable and excusable noncompensable delays caused the project to slip justifiably by 72 days.

Figure 7 illustrates the first delay analysis CPM schedule. Once the first delay analysis was completed, a duplicate of the project file was made to maintain a record of the delay analysis.

An important step to perform prior to progressing to the next delay analysis is to verify the activity duration and relationships. This was not necessary in the case study, since the changes to the method of construction (activity duration and relationships) that might occur as a result of the delays were not incorporated.

The second delay analysis was done by using the adjusted as-planned schedule from the first delay analysis as its starting point. Again, all project data were exported from the adjusted schedule to a WK1 file. Activities that were not delayed during the second time period between 1 May 1990 and 31 December 1990 were removed. Referencing the as-built listing for the delayed activities, the remaining duration and information of delayed activities (Table 1) were imposed on the second WK1 file that contained delayed activities between 1 May 1990 and 31 December 1990 as shown in Figure 6. This information was imported back into Primavera for the second analysis. The adjusted schedule with the revised information was recalculated which generated a second adjusted completion date. This second adjusted completion date of 28 March 1991, compared against the previous adjusted completion date of 15 November 1990, indicated that excusable compensable and excusable noncompensable delays caused the project justifiably to slip another 87 days.

Figure 8 illustrates the second delay analysis CPM

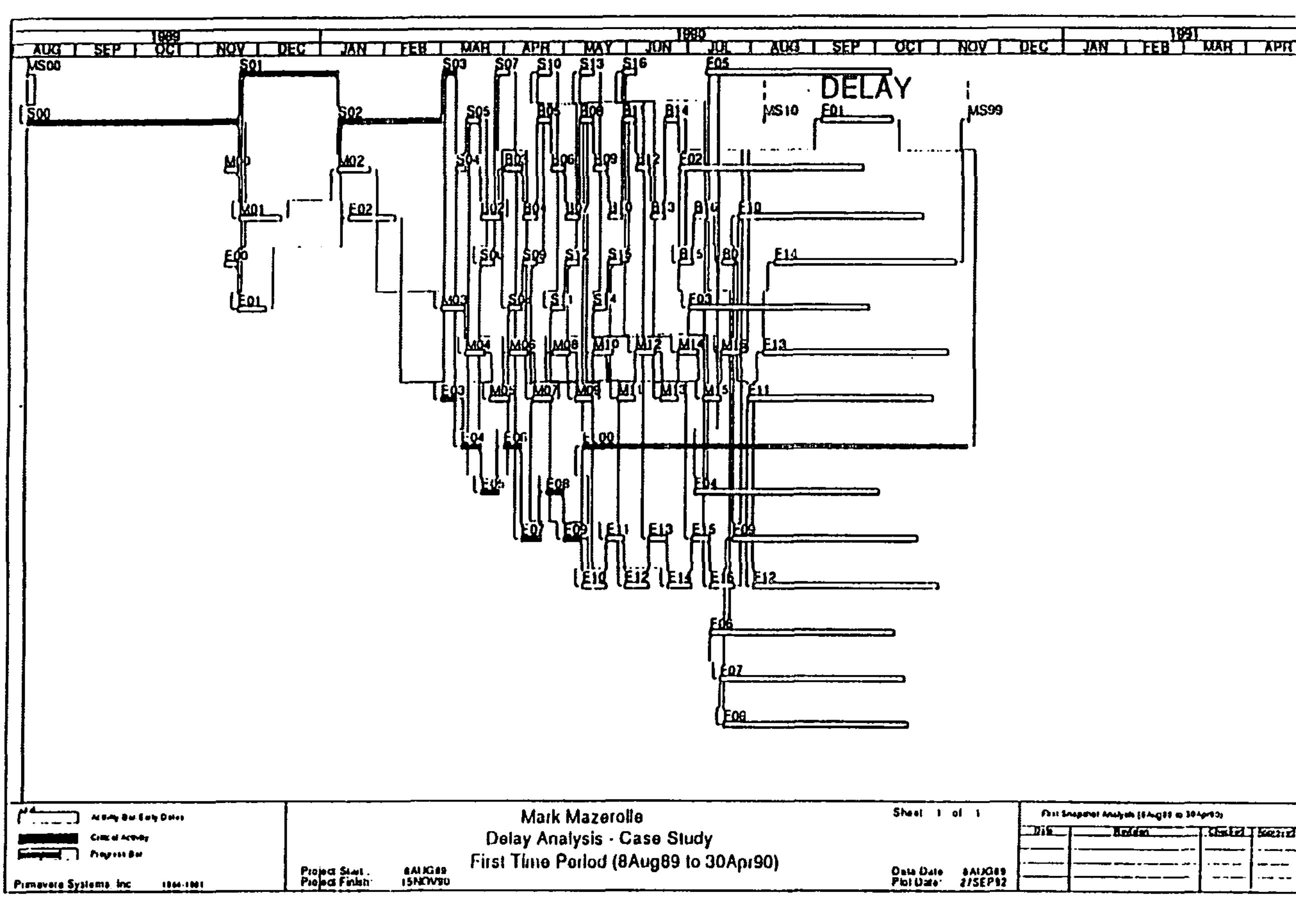

Figure 7 Case study's first delay analysis (8 August 1989 to 30 April 1990)

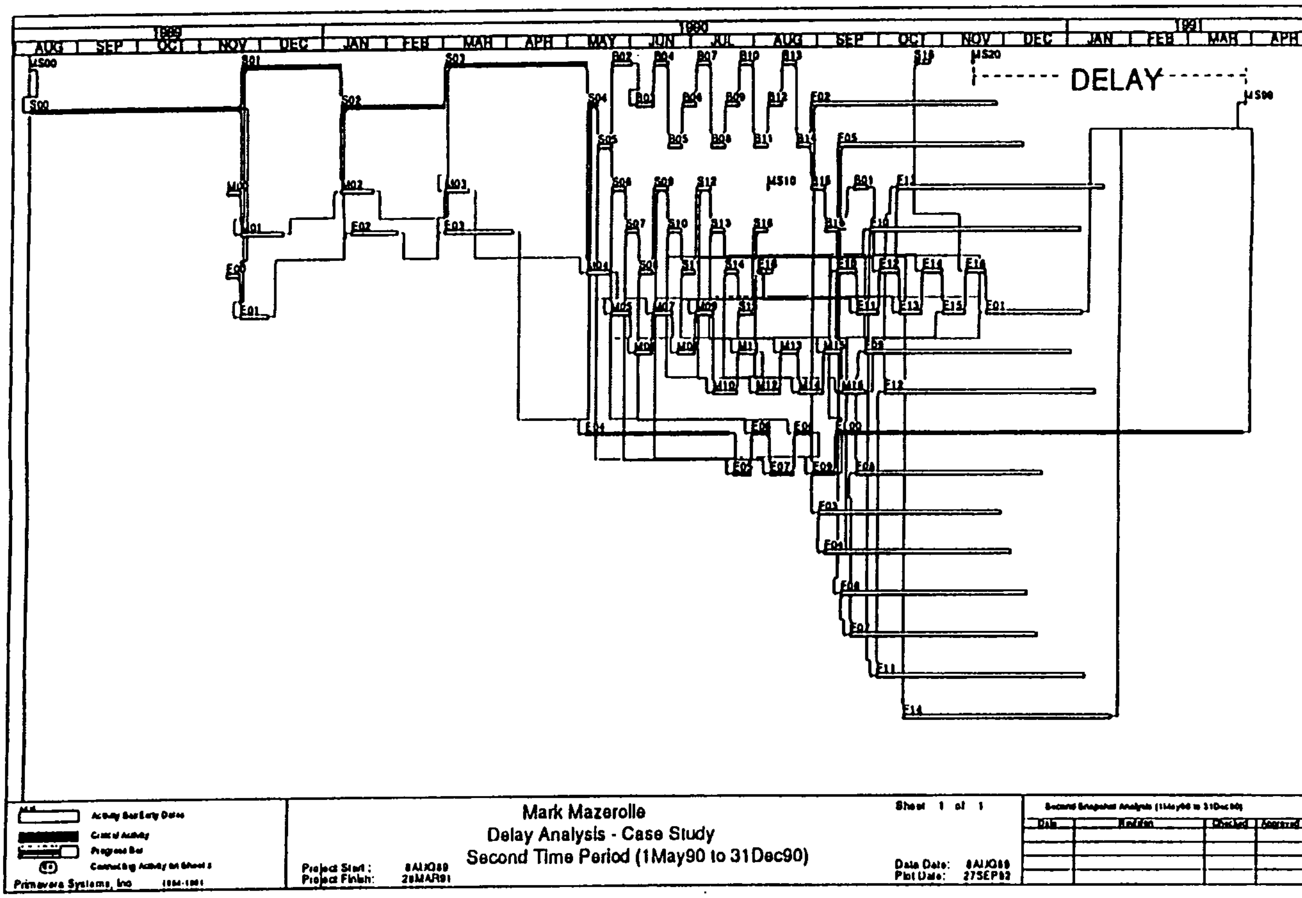

Figure 8 Case study's second delay analysis (1 May 1990 to 31 December 1990)

schedule. Again, a duplicate of the second delay analysis project file was made.

The third and final delay analysis was done in a similar manner to that of the first and second analyses. Activity data were exported from the second adjusted schedule and all non-delayed activities that fell within the last time period (1 January 1991 to 19 July 1991) were removed. The remaining activities (Table 1) were then modified to reflect the delays they encountered. The updated WK1 file was then imported back into the adjusted schedule from the second delay analysis. Data on the delayed activities between 1 January 1991 and 19 July 1991 (Figure 6) were imported back into Primavera for the third and final analysis.

The final adjusted completion date of 1 April 1991, compared against the second adjusted completion date of 28 March 1991, indicated that excusable compensable and excusable noncompensable delays caused the project to slip justifiably another 2 days. Figure 9 illustrates the final delay analysis CPM schedule.

Once the delay analysis on the case study was completed, the effect of excusable compensable and excusable noncompensable delays on the project completion date could be quantified. By summing up all the differences in completion dates that had occurred from the delay analyses of the three time periods, a total of 161 days (72 + 87 + 2) of delay to the as-planned project completion date had been accumulated. Thus it could be stated that in this case study, the contractor was justifiably delayed by 161 working days due to both excusable compensable and excusable noncompensable delays.

Findings of system validation

The CDCA approach to claims analysis worked well in both the project control and claim analysis phases of the case study.

The project control phase of the case study documented the progress of the project through four updates. Based on the information used, the project's completion date was extended from 7 August 1990 to 19 July 1991, an overrun of 49 weeks. In addition, a comprehensive package of project documentation containing delay information was generated. Since Primavera has a 'log' window which enables the user to input delay information directly, as well as enabling the user to define a coding system to tag any activities which have delays, it is

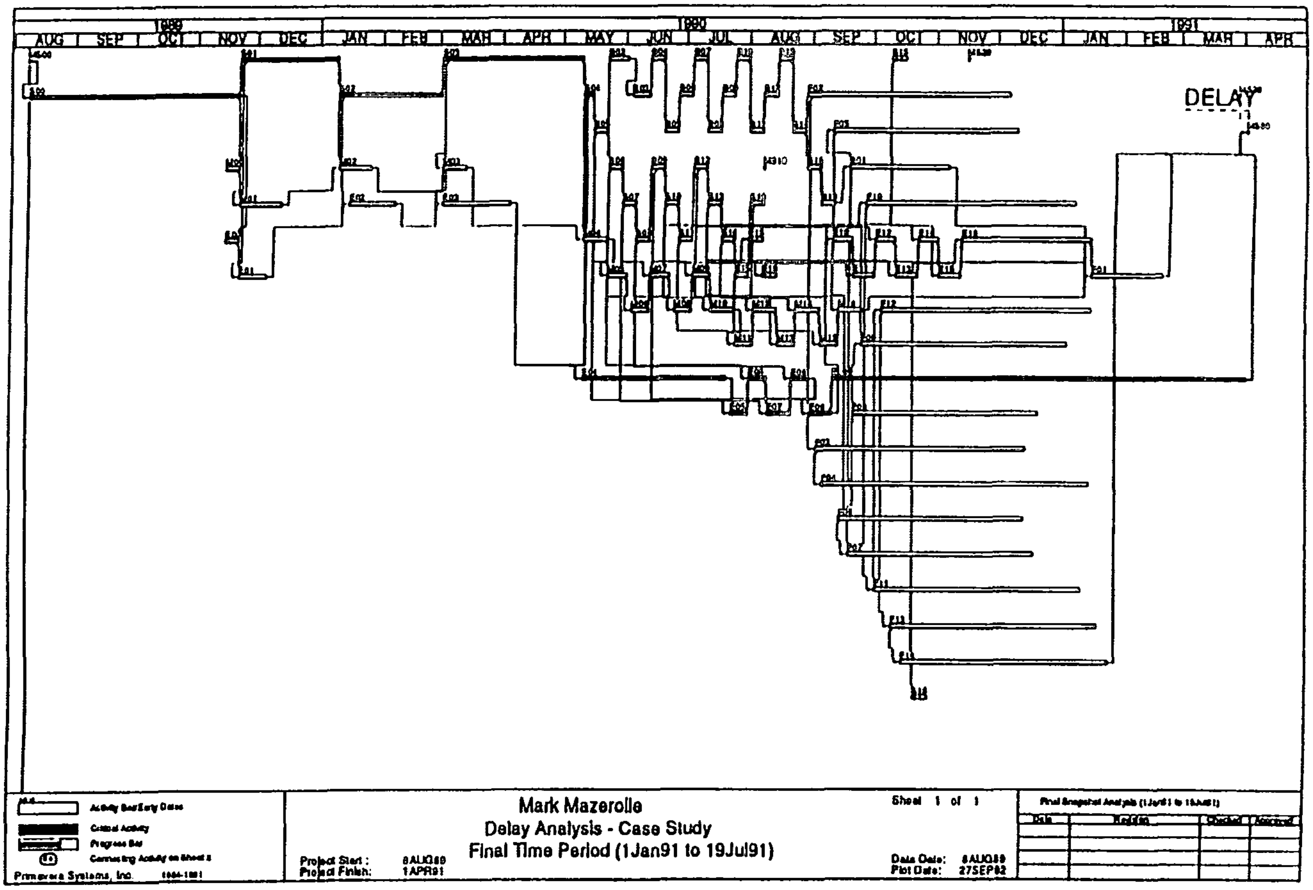

Figure 9 Case study's final delay analysis (1 January 1991 to 19 July 1991)

debatable if exporting project data to a database is essential when using Primavera. On the other hand, if the project management software lacks the ability to 'log' or 'code' data, then exporting project data to a database is essential. Another key advantage of exporting project data comes when large amounts of information need to be updated. Working in the database format can be much quicker.

The claims analysis phase of the case study involved performing a delay analysis using the project information that was documented in the project control phase. Three time periods were used to determine the effect of excusable compensable and excusable noncompensable delays on the project's completion date. The total number of days the contractor was justifiably delayed on the project due to excusable compensable and excusable noncompensable delays was 161 (72 + 87 + 2) working days.

The isolated delay type (IDT) technique used in the delay analysis worked out well in determining the effect of the delay(s) on the project's completion date. Although this technique dealt with concurrent delays amongst activities, the assessment of concurrent delays within activities would still have to be addressed manually, prior to the delay analysis. This is another area where an expert system can aid practitioners in the assessment of delays.

When performing the delay analysis, the process of exporting activities to a WK1 file, modifying specific delayed activities, importing the WK1 file back into Primavera, and re-scheduling to see the effect of the changes, worked extremely well. The technique of using a database to modify specific data and importing them into the scheduling package, even without extensive delay information previously documented, in itself is beneficial. However, following the integrated system approach to claims analysis, where delay information has been documented and is readily available in the proper format, made the delay analysis fast, easy and effective.

CDCA implementation and limitations

The system is designed to run on a PC (personal computer) that requires basic computer hardware and a management software, a dbase/spreadsheet software and the delay advisor expert system that runs in the VP Expert (Sawyer, 1989) shell environment. A ruled-based expert system development tool, its main features include: backward chaining, automatic goal generation, allowing for confidence factors to be assigned, explanation facility during a consultation, interface with databases, spreadsheets and external procedural routines. The latter is particularly important because the equipment selection problems involve the processing of both heuristic knowledge (rules of thumb) and external programs in dealing with algorithms, for example calculation of costs.

Limitations of CDCA arise from the system's components which are not yet fully integrated and often need the interference of the user. It is also limited by the knowledge stored in the delay advisor knowledge-base and the ability of the project team to collect and store data on the delays. The expert system was originally developed to aid inexperienced personnel within construction companies predicting the validity of a claim and delay analysis.

One of the major difficulties encountered with the package was the ability of the shell to handle the number of rules to develop this system (500). Several sub-knowledge bases were combined together using the 'chain' command.

Conclusions

Delays on a construction site are inevitable, and as a result many construction jobs end up in litigation. Present methods of analysing delays and preparing claims are inaccurate, time consuming and costly. In an attempt to overcome the problem of sorting through quantities of project documentation and improve the process of delay analysis, an integrated computer-based system (CDCA) was introduced.

The system utilizes a database management system of stored and organized project information. This can reduce the cost and time associated with claims preparation. It integrates existing management software tools and is designed to accommodate four major components, namely the user, project management, database management/word processing and an expert system. The system is designed to provide two key functions, the project control and claims analysis capabilities.

CDCA requires that from the start of the project (the project control phase), project data to be updated are exported from the project management software into a format which can be edited by database software. If delays are encountered, the cause and classification of the delay type (be it excusable compensable, excusable noncompensable or nonexcusable) are assessed and documented immediately. Once the project data have been updated, they are imported back into the project management software and an adjusted schedule is generated. The integrated system updates project data, assesses delays and documents delay information as it happens. Thereby in the event of a claim, a major part of the data gathering is already done, thus reducing the cost of claims preparation.

CDCA has been validated using a case study. The results of the case study were very encouraging. Having delay information documented and readily available to manipulate made the delay analysis fast, easy and effective. The isolated delay type technique used in the delay analysis worked out well in determining the effect of the delay(s) on the project's completion date.

Delays are costly to all parties involved in the construction industry, especially in cases where they result in litigation. The time and expense incurred to prepare claim documents in itself is substantial. There is room for improvement in present practices for keeping track of delays. Thus, an integrated system to aid in the analysis of a claim arising from construction delays can be valuable.

Presently, the systems approach is not fully automated. Further research into the automation of the integrated software, specifically full integration between project management, database, and the expert system would be the next step to pursue.

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