A Computer Integrated System for Construction Delay Analysis: Time and Impact Costs

Mireille Battikha

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ABSTRACT

A Computer Integrated System for Construction Delay Analysis: Time and Impact Costs

Mireille Battikha

In recent years, considerable attention has been directed towards ascertaining the nature of disruptions in construction contracting. In practice, attempts are made to identify the causes of delays, modify the schedule by incorporating revised durations, and determine the impacts associated with the new project time. The analysis itself is usually complex and can be aided by a computerized approach.

In this work, the advantages and the shortcomings of the existing delay analysis techniques are highlighted and a new delay analysis technique is developed and tested. A methodology to quantify impact costs related to loss of productivity, is also proposed and discussed. In addition, both the delay analysis technique and the cost calculation methodology are accommodated within a computer integrated system, that is demonstrated and validated using a real case study. The developed system comprises of integrating existing management software tools, including: project management, database/spreadsheet, and an expert system. It is designed to assist practitioners in saving both time and money in the preparations of claims arising from delays.

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To my daughter, Mia

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CHAPTER I

INTRODUCTION

1.1 Background

The construction industry is one of the largest dollar generating segments of the canadian economy. Thus, individual contracts or projects can and often involve huge sums of money to be expended over long periods of time. According to Statistics Canada, about $94 billions have been spent on construction projects in 1993, which amount to almost 13.5% of the Gross Domestic Expenditure (Statistics Canada).

The construction environment is sensitive to disputes. Nearly each party in the construction industry is involved in a dispute today. The owner usually has disputes with contractors, construction managers, and designers. The contractor has disputes with architects or engineers, clients, subcontractors, suppliers, etc. Time is the key to construction disputes (Hohns 1979). Although these disputes originate from a variety of causes, delays remain their origin.

An important measure of success in the management of construction projects is the achievement of the completed project within the prescribed scheduled duration. Even with today's technology, construction projects continue to suffer delays, as things go wrong and their completion dates get pushed back, with hopefully someone else to be blamed.

In construction, delay means the time overrun either beyond the contract date or beyond the date that the parties agreed upon for delivery of the project (O'Brien 1976). To the owner, delay can mean loss of revenue. To the contractor, delay means higher indirect costs such as overhead costs, and higher direct costs including material, labour, equipment, and escalation costs. Delays can be due to strikes, rework, poor organization, material shortage, equipment failure, change orders, act of God, etc. Delays are costly to both parties, the contractor and the owner, and commonly produce claims by one party to the contract on the other party.

Construction claims arising from delays are a common occurence of most construction projects, and among the most complicated and difficult to analyze. A claim is a demand for something rightfully or allegedly due (Webster 1991). A claim is also defined as "a request, supported by full details and particulars, for something that one party believes it is entitled to (usually time or money or both), by virtue of a term or terms in a valid contract with another party but for which there is as yet no agreement" (Worby et al. 1985). In a delay claim analysis, the two concepts used are time and money (Rubin et al. 1983). Costs resulting from delays represent substantial percentages of the overall contract value (O'Brien 1976). As the cost of individual projects increases dramatically, the cost of delays seems to increase at an even greater rate (O'Brien 1980).

Claims could reach litigation, and are expensive, time consuming to both parties, and wasteful of engineering talent. The direct costs of litigation usually translates into some 15% of the money that crosses from party to party (Hohns 1979). The magnitude of construction claims represents a substantial amount of the total contract award values, (McManus 1990), while the number of submitted claims is increasing every year (Clark 1990).

Preparing a claim analysis dealing with delays is a complex process, it involves, a lot of data collection, schedule impact analyses, costs quantifications, and presentations. This process requires exhaustive tedious manual work. A major litigation can sometimes demand reviewing tens of thousands of documents. Project documentation plays an important role in establishing the facts and proving their evidence (Fitzgerald 1980, O'Brien 1980, Wilson 1982, Ponce de Leon 1992, Smith 1992, Goodwin 1990, Yates et al. 1990). The presentation of the claim is extremely important, since the claim is almost never ruled upon by the people who are most knowledgeable of what went on (Hohns 1979). The process is complex and requires time, money and effort.

The incorporation of computers into the daily operation of construction firms since the 1970's allows to process data rapidly and efficiently, to simplify overdone work on papers and to present clear and concise analysis processes. Establishing an adequate and effective computerized delay claim analysis procedure for determining entitlements and quantifying damages will be of great value to the construction industry in claims resolutions. This is the focus of this research work.

1.2 Delays: The State-of-the-Art

Delays have been encountered in the construction process since the concept of time has been introduced to the completion date of projects. Researchers classified delays according to liability. They highlighted the benefits of using CPM schedules in the time impact analysis, and emphasized on the importance of documentation in the claim preparation procedure and the calculation of costs due to delay damages (O'Brien 1976, Hohns 1979, Rubin et al. 1983, Simon 1979, Hartigan 1980, Walstad et al. 1980a, 1980b, Bramble 1987, Ponce de Leon 1991b, Rusteika 1991, Zack 1992; 1993), while Neil (1991) described the application of a decision analysis for submitting a claim.

A delay analysis is a procedure that involves the use of network-based scheduling tools to identify, quantify, and explain the cause of a schedule variance. Finding the links between the cause and the effect of damages with the entitlements associated with schedule impacts is necessary in resolving claims in today's construction environment. This has interested many researchers (Galloway 1981, Mortensen 1988, Ockman et al. 1988, Fredlund 1990, Saad 1993, Scott 1993). A technique to analyze concurrent delays using the application of microcomputers was provided (Kraiem 1984, Kraiem et al. 1987), and an automated approach for analyzing delays was proposed (Reams et al. 1987). Others (Asselin 1980, McCullough 1989, Ponce de Leon 1991a) focused on the use of CPM schedules in construction claims, while the substantiation and use of the as-planned schedule in a delay analysis have been examined (Reams 1990, Popescu 1991). Some researchers (Arditi et al. 1989), described a method to calculate the costs of the owner-directed acceleration, and to apportion the costs between owner and contractor, the impact of delays on the project duration was calculated using the time impact technique. The different existing delay analysis techniques used in measuring the time variances of schedules due to delays were investigated (Leary et al. 1988). Those techniques were further assessed (Mazerolle et al. 1993), and a new delay analysis technique was proposed called the Isolated Delay Type technique.

Diekmann et al. (1984) presented the first attempt at developing a construction contract legal analysis computer system, called Differing Site Conditions Analysis System, and based on the techniques of Artificial Intelligence, mainly the Knowledge Based Expert System. Computer applications in claims analysis, and 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 Microship" (1987), can be used in identifying various entitlement issues. Another developed KBES (Cobb et al. 1986) in analyzing claims improved on the computerization of construction claims, focusing on the Expert System in analyzing the differing site conditions disputes. Other researchers, (Kraiem et al. 1988, Diekmann et al. 1990), have elaborated on how this can be achieved, while some (Riad et al. 1989), used the KBES to manage time-based claims, the system 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. Bubbers et al. (1992) have provided a computerized assistance in settling construction contracts claims, by using the Hypertext approach, which provides information on relevant cases, however it has no decision-making capability like the expert system. Baram (1992) discussed the need and goals for a computer system to analyze delay claims.

To simplify the record-keeping and retrieval procedures, computer applications in the construction industry reached the computerization of daily site-reporting system for collecting accurate field data that builds upon the conventional, superintendent's daily report. The system developed by Russel (1993), integrates site reporting, project planning, and scheduling, it also documents the field experience in a form that is useful for dispute resolution. Some researchers (Barnes 1993, McCullouch et al. 1993) described the use of computers at the jobsite. An integrated computer-based system that aids in the analysis of claims due to delays, was proposed (Alkass et al. 1987, 1991, 1993). The system was improved (Mazerolle et al. 1993) to include a delay analysis to measure the time magnitude of the delays. Yates (1993), presented the Delay Analysis System for determining possible causes of delays and feasible alternatives to prevent further delays. Carr (1993), demonstrated how generic microcomputer software can be used to develop an integrated cost/schedule control system. Cost variances, schedule variances, and delays are represented in a four level hierarchy of work packages. In addition, an integrated computerized system that can be used as a dispute-resolution tool for managing owner-directed acceleration was described (Riad et al. 1994).

Costs of delay damages could be calculated after determining the liability of each party (Mitchell 1977, Richter 1977, Koehn et al. 1978, Hohns 1979, Hart 1980, James 1980, Clark 1984, McDonald 1992), however quantifying impact costs related to productivity loss has been a major concern to researchers (Brunies 1988, Heather 1989, Revay 1990). While some have established relationships between change orders and productivity loss, (Leonard 1988, Moselhi et al. 1991), others described a knowledge-based approach to quantify impact costs (Nicholas 1989, Moselhi et al. 1990).

Despite the diversity of these contributions, the process of delay claims analysis has not been simplified, and the analysis of delays, regarding time and cost needs improvement, as well as the process of managing these analyses.

1.3 The Rationale

The primary objective during the construction process is to complete the project on time and within the budget while meeting established quality requirements and other specifications (Rasdorf et al. 1992). Unfortunately delays are becoming an integral part of a construction project and the basis for most construction claims.

Collecting documents and analyzing impacts while preparing claims require a lot of time and effort. Therefore, it is a costly process. With the deficiencies of the present methods of analyzing delays and quantifying damages, improvement is required in many respects. The facts relating to a claim must be fully and clearly presented. Schedule variance analysis is a crucial tool to identify, quantify, and explain the causes of delays due to each party. Therefore, it must be accurate, effective, and objective. The basis for calculating costs should be accurately and persuasively presented, demonstrating that the settlement is in accordance with the compensable damages determined in the analysis and agreed upon in the contract. In addition, quantifying the costs incurred in delays needs to be performed using convincing and effective methods. The claim must be presented with its cost items organized so that it can be audited accurately and readily (Netherton 1983). Thus the need for an adequate computerized tool in supporting the analysis of delay claims, irrespective of the method of resolution provided, be it negotiation, mediation, arbitration, litigation, Board of Contract Appeals, or Alternate Dispute Resolution (Clavier 1992, Spittler 1992).

Since construction claims present engineering and legal problems, a system that reduces innaccurate analysis and provides a better way of communication between legal and construction knowledge, being time-saving and cost-efficient, will be mostly valuable in construction disputes resolutions. However, a successful system for settling claims is not only a potential for improvement of claims administration but extends to preventive measures.

1.4 Objectives

The main purpose for conducting this research is to develop and present a tool for analyzing delays and quantifying their damages, in order to assist management teams and analysts, be it with the owner's or contractor's organization involved in construction projects, in claims preparation, in performing the analysis more effectively and economically.

In order to reach this goal, several objectives were set for this research, and are listed as follows:

1. Acquire a good understanding of the current practice in analyzing construction delays.
2. Propose a new and effective delay analysis technique, capable in measuring the impact of delays on the project duration, while identifying the liable party.
3. Introduce a methodology for quantifying impact costs related to productivity loss due

to compensable delays.

4. Accommodate both, the proposed delay analysis technique and the new impact cost calculation methodology within an integrated computer-based system.

The proposed system would be capable of assisting the personnel involved in claims management to provide better analyses of delays and claims preparations thus saving time and money.

1.5 Scope and Organization of Thesis

The fundamental idea of this research consists of developing an integrated computer-based system used for delay claims analysis. This system comprises of integrating existing management software tools such as project management, database management and spreadsheet. In addition to these, a Knowledge Based Expert System tailored to the proposed imtegrated system, is used to facilitate the decision making process in determining the type of delays involved and the nature of entitlements. However, the Expert System has been developed by others and is used in the present work.

Chapter two discusses the types of delays encountered in the construction process and the different schedules used in a delay analysis. In addition, the various delay analysis techniques currently used in measuring the effect of delays on the project completion date are outlined. Damages and costs due to delays are described, as well as the existing methods for quantifying impact costs related to productivity loss.

Chapter three investigates the existing delay analysis techniques. Since there are several techniques and procedures available for schedule impact analyses, an assessment of their effectiveness in measuring the impact of delays on the project completion date is performed. Using a common test case and applying each technique, the advantages and shortcomings of each delay analysis technique are highlighted, and a new delay analysis technique is proposed.

Chapter four focuses on introducing a new methodology to quantify impact costs related to productivity loss. Several existing methods are examined in order to determine their shortcomings and their attributes, and a linear regression model is established between the percentage extended duration of the project due to compensable delays, and the percentage productivity loss.

Chapter five is devoted to the description of the proposed computer integrated system for claims delay analysis associated with construction, its components and the methodology behind its development.

In chapter six, the validation of the proposed system and its capabilities are presented. The system is tested by applying it to a real construction project which had already undergone a claim analysis. Testing the system includes the proposed delay analysis technique, and the newly developed methodology for quantifying impact costs due to productivity loss.

Finally as a closure to this thesis, chapter seven presents conclusions and recommendations for further research concerning the application of this system in the process of construction claims resolutions, and the potentials of its expansion. The schedule reports of the case study are provided in an appendix.

1.6 Methodology

The first part of the research involved a thorough literature review, in order to study the current practice in analyzing delays. A systematic analysis was performed utilizing a test case network, to assess the currently available delay analysis techniques, outlining their advantages and deficiencies, and a new delay analysis technique was developed. By investigating the existing methods for quantifying impact costs related to productivity loss, their attributes and shortcominngs were highlighted, and a new methodology for estimating these costs was introduced. Both, the delay analysis technique and the impact costs quantification methodology were accommodated within a computer integrated system, including existing management software. The developed system was tested against a real case study to determine its validity and capabilities. Correspondence, searching through claims reports, and personal interviews with practitioners were carried out to collect data and inquire knowledge about construction delays analyses, and costs quantification.

CHAPTER II

BACKGROUND

2.1 Introduction

In settling claims arising from delays, the entitlement, the causation, and the effect are taken into consideration, thus involving a delay analysis. Delays can be caused by different parties, and consequently the effects and compensations vary for each case. The assessment and quantification of the impact is performed with schedule analyses and depend on the types of delays that are classified according to liabilities and the time of occurence of the events. Therefore, it is important to understand the various types of delays and how they have been upheld by courts when damages are being claimed, be it extra time, money, or both. In this chapter, the different types of schedules used in a delay analysis are highlighted, and the existing schedule impact analysis techniques currently utilized in industry are investigated, in order to recognize the diversity of these approaches in measuring delays. In addition, costs of delay damages caused by each party, as well as the existing methods for calculating the impact costs related to productivity loss, are also explored.

2.2 Construction Delays

The principal dimension measured by schedules is delay (O'Brien 1980). Delays may affect the completion date of a project or milestone activities. There are four general categories of responsibilities for construction delays (O'Brien 1980):

1. Owner (or his agents) being responsible.
2. Contractor (or his subcontractors) being responsible.
3. Neither contractual party being responsible.
4. Both contractual parties being responsible.

2.2.1 Types of construction delays

Delays are many-faced and induced by various events or reasons. According to the American Institute of Architects general conditions of contract, a classic delay occurs when a period of idleness and/or uselessness is imposed upon the contractual work. Such delays can be classified according to liability into the two major types: Excusable and Nonexcusable.

i) **Excusable Delays** are those not attributable to the contractor's actions or inactions. Excusable delays when founded, entitle the contractor to a time extension, if the completion date is affected. They may also impact non-critical activities or milestone activities. This occurence needs a more detailed analysis to determine whether additional time extension is given or if the reduction of float time can be justified. Excusable delays can be further classified into Compensable and Noncompensable delays (Sweet 1977).

Excusable Compensable Delays are caused by the owner's actions or inactions. Furthermore, the contractor is entitled to a time extension and damage compensation for extra costs associated with the delay. Delays caused by owners can include, but are not limited to (O'Brien 1980, Poulin 1985):

- 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;
- Interference by other prime contractors working for this owner.

The owner is also subject to the consequences of acts by his designated representative, or agents, including the architect/engineer and/or the construction manager. The causes of these delays can include, but are not limited to (O'Brien 1980):

- 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 Noncompensable Delays are neither the contractor's nor the owner's fault.

The contractor would only be entitled to a time extension since there are no grounds for delay damage compensations. These delays are due to unforseen reasons beyond the control and without the fault and negligence of the contractor. Such delays are usually provided for in the contract under "Force Majeure". Those causes of delays include but are not limited to (O'Brien 1980, Poulin 1985):

. 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, floods, epidemics;

. Quarantine restrictions;

. Strikes;

. Unusually severe weather

. Freight embargoes; and,

. Delays of subcontractors or suppliers due to similar causes.

ii) **Nonexcusable Delays** are caused by the contractor's or its subcontractor's actions or inactions. Consequently, the contractor is not entitled to a time extension or delay damages, however the owner is entitled to liquidated or other damages. The causes of these delays include, but are not limited to (O'Brien 1980, Poulin 1985):

. Slow to mobilize;

. Failure to man the project;

. Failure to provide sufficient equipment;

. Poor workmanship;

. Failure to coordinate;

. Inadequate supervision;

. Unforseen accidents;

. Cash flow limitations;

. Poor productivity;

. Subcontractor performance;

. Bankruptcy of subcontractor or supplier;

. Late delivery by supplier;

. Rejected material or equipment;

. Bid shopping; and,

. Poor planning.

For the purpose of quantification, and depending on the timing of the events, delays can be further classified at the activity level as follows (Kraiem et al. 1987, Riad et al. 1989, O'Brien 1980, Rubin et al. 1983, Bramble 1987):

a) Independent or Classic 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 the total project duration, and to allocate cost burdens to the parties involved in that delay (O'Brien 1980).

b) Concurrent Delays

Concurrent delays occur when two or more delays occur during the same time period, or overlap to some degree, either of which, had the delays occurred alone, they would have affected the ultimate completion date (Rubin et al. 1983). It is difficult to apportion damages if the concurrent delays are due to both the owner and the contractor (Bramble 1987). In analyzing these delays, each is considered independently and its impact on other activity and the project duration is calculated. Special care must be taken to noncritical activities affected by the delay, specifically to the float effect.

Rubin et al. (1983), suggested the following guidelines for classifying these kinds of concurrent delays:

. If excusable and nonexcusable delays occur concurrently, only a time extension is granted to the contractor.

. If excusable compensable and excusable noncompensable delays occur concurrently, the contractor is entitled to time extension, but not to damages.

. If two excusable compensable delays occur concurrently, the contractor is entitled to both time extension and damages.

This adjustment of entitlement is valid if the concurrent delays happen on a critical path (Kraiem et al. 1987). Although such guidelines are useful for a delay analysis, it is in the best interest of all parties involved in a construction project to agree at the start, about the definitions of such delays and to accommodate them into the contract language.

c) **Serial Delays**

Serial delays occur when a series of delays are linked together, sometimes of different causes (O'Brien 1980). In this type of delay the action of one party can cause a series of delays in a number of succeeding activities (Riad et al. 1989). Thus, the effects of a delay may be amplified by a following delay (O'Brien 1980).

2.2.2 Float versus critical

Float time is a valuable concept in scheduling, since it indicates those paths of activities where some flexibility is allowed in the scheduling of work (Hendrickson et al. 1989). Moreover, noncritical activities may become critical when float time is used up by the delay. The problem arises when the float is consumed by delays, and the party that owns the float applies the first come first serve basis (Ockman 1988, Fredlund et al. 1992). Several opinions on the use of floats have been discussed in the literature (Householder et al.1990, Zack 1991). Be it owner or contractor, the float belongs to the project, and when exclusive use of the float by one party is determined at the undue expense of the other, an adjustment is required. Since the float could impact the whole project duration, the exclusive use of float by on party should not be at the expense of the other (Hohns 1979). Rather than introducing adversary relationships on projects, it is good to recognize that float exists for the benefit of all participants (Richter et. al 1982, Harris et al.1989). There are a number of contracts that do not clearly state which party will receive the benefit of float time. However, some Government contracts expressly state that float time is not intended for the exclusive benefit of either the contractor or the owner, and that the contractor will not be entitled to an extension of time unless the delay directly affects the critical path. In case of a delayed noncritical activity, these provisions require that the delay exceed the float time along the path containing the float (Rubin et. al 1983).

2.3 Schedule Variance Analysis

Any time-related schedule variance problem needs to be resolved according to three basic elements of time impact namely: causation, liability, and damages. The objective of the analysis is to measure the magnitude of the time impact due to the responsible party and determine the corresponding damages. Several scheduling documents are utilized in analyzing the time impact on the project completion date. Scheduling techniques (critical path methods or bar charts) are normally used to evaluate delays resulting from a specific impact.

2.3.1 The As-Planned schedule

At the start of each project, an original work schedule is prepared by the contractor in accordance with the contract documents (Arditi et al. 1989, Riad et al. 1989, Alkass et al. 1991), which is the as-planned schedule. This schedule reflects the contractor's planned approach to pursue the work, and illustrates only the planned activities, their duration, their relationships, the critical paths, and the project start and finish dates. In order for this schedule to be accepted in a delay analysis, it must show that the relationships between activities are reasonably valid, the durations realistic, the planned resource allocation feasible, and the schedule has allowed for foreseen conditions such as weather conditions, work restrictions, constraints, and time for inspection and approvals (Reams 1990).

2.3.2 The As-Built schedule

As the job progresses, new conditions appear and the schedule is updated in order to recalculate the new project duration if it had been impacted. Thus at the end of the construction project, a new schedule is established which is the as-built schedule (Arditi et al. 1989, Riad et al. 1989, Alkass et al. 1991). This schedule could also be prepared from the project records (Alkass et al. 1991). The as-built schedule reflects the actual succession of events that took place during the execution of the project, while the facts are taken from the project progress reports, data and documents.

2.3.3 The Adjusted schedule

To explain the sequence of events which transform the as-planned schedule into the as-built schedule, a series of adjusted schedules are prepared thus explaining the major schedule variances which occurred during the course of the project (Arditi et al. 1989). The adjusted schedule reflects how the as-planned schedule has been affected by delays, accelerations, or other changes, when they are incorporated in the schedule.

2.3.4 The As-Projected schedule

During the updating process, if the project is not yet complete, an as-projected schedule is performed which will show the expected project completion date. This schedule includes the as-built data for the completed part of the project and the proposed changes in the remaining portion (Arditi et al. 1989).

2.3.5 The Entitlement schedule

Entitlement schedules are also used in order to determine the impact on the project completion date, due to excusable delays (Reams 1990). They also depict the difference between the adjusted and the projected completion dates. Care has to be taken in these procedures, since the critical path analysis is a dynamic phenomenon, and might reflect a theoretical path different from the real one, when only some impacts are incorporated in the as-planned schedule.

2.4 Existing Delay Analysis Techniques

The Critical Path Method (CPM) is necessary to help evaluate the cumulative effect of delays on the project duration. The CPM is superior and used more often than the bar chart method in claims situations (Hohns 1979). If a CPM as-planned schedule does not exist, a claim analyst must prepare one from the contractor's bar chart (Reams 1990).

In the past, delay claims were based on the "barnyard door" (McCullough 1989). This was a narrative approach of the delays with an attached bar chart, comparing the as-planned to the as-built schedules, without a cause-effect link analysis. All data and reports were presented in hope of getting some compensation. Neither party knew exactly what delays were justified. So claims were escalated, and settlements were low and unfair.

Several techniques and procedures for analyzing schedule impacts have been currently recognized by legal authorities to determine the effect of delaying events upon the total project duration. An event may delay an activity, but not the overall project. Those delays are to be analyzed according to the right of using the float. Not all the available schedule impact techniques are appropriate to analyze delays in a given situation. Determining the impact technique depends upon the analyst judgement and expertise (Leary et al. 1988). The most common techniques currently available to be used in the construction industry include: Global Impact, Net Impact, But For (or Collapse), Adjusted As-Built CPM, Snapshot, Time Impact, Isolated Delay Type, and Concurrent delays analysis.

2.4.1 Global Impact technique

The global impact technique is a simplistic approach to depict the effect of delay causing events. It is often used by claimants in their initial requests for time extension, usually during the construction phase. In this method, all the delays, disruptions, and similar occurrences are simply plotted on a summary bar chart. The delay start and finish dates are determined for each event, and the duration of each delaying event is computed. The total delay to the project is calculated to be the sum total of the durations of all delaying events (Leary et al. 1988).

2.4.2 Net Impact technique

This method depicts only the net effect of all claimed delays on a bar chart. In implementing this technique, all delays, disruptions, and suspensions, even change orders are plotted on an as-built schedule. The main argument focuses on the combined overwhelming effect of all delays on the completion date of the project. Thus only the net effect of delays is calculated and the requested time extension is then the difference between the as-planned and the as-built completion date. The net impact technique unlike the global impact is an attempt to deal with the issue of concurrent delays (Leary et al. 1988).

2.4.3 Adjusted As-Built CPM technique

This technique utilizes the CPM format to develop an as-built schedule for the entire project. Delaying events are depicted as distinct activities and linked to the specific work activities in the network by restraints. The "critical path" of the project is determined twice, once in the as-planned schedule and once at the end of the project. The difference between the adjusted as-built completion date and the as-planned completion date is the amount of time the claimant would ask for compensation. The as-built CPM method may weed out minor delays that would not affect critical activities. This technique is similar to the net impact technique in that both methods only show the net effect of all claimed delays on the project completion date (Leary et al. 1988).

2.4.4 But For (Collapse) technique

The basic concept of the But For technique is that the opposite party can be shown to be liable through a CPM analysis, that deals with the two parties' impacts separately. Delaying events for which the claimant is willing to accept responsibility are incorporated into the as-planned CPM schedule, and the recalculation of the project completion date is performed. The as-built schedule is compared to the adjusted schedule (calculated), and the conclusion thus drawn is that the difference between the as-built and the revised project completion dates is the time effect of delays which were beyond the claimant's control. The duration of the claimed delays will be subtracted out from the total variance, leaving the balance to the other party (Leary et al. 1988). "But For" the other party's delays, the project would have been completed in a timely manner.

If the contractor is using this technique the analysis would include only nonexcusable (contractor's fault) delays into the as-planned schedule. The result of the adjusted schedule would generate a revised completion date, which is due to the contractor's delays. The difference between the as-built and the revised completion date is due to the owner. The logic is that despite all of the contractor's delays the project is still impacted which is the responsibility of the owner, and the rest of the total delays is due to the contractor. Conversely, the owner can use the same technique, but would include into the as-planned schedule, only excusable delays for which the owner accepts responsibility.

2.4.5 Snapshot technique

The Snapshot technique is used to determine the amount of delay that has occurred on a project, the time when the delay occurred, and what was the cause(s) of the delay (Tardif 1988). The snapshot technique utilizes the as-planned, the as-built and any revised schedule that have been implemented during the execution of the project. The total project duration is divided into a number of time periods, or snapshots. These snapshot dates are usually selected to coincide with major project milestones, significant changes in planning, or when major delays or group of delays are known to have occurred. For the first snapshot the analysis starts by inserting the delaying events into the as-planned schedule, and a new schedule duration is generated. In the next snapshot the durations and the relationships of the activities are taken from the as-built schedule, for the snapshot period, and are incorporated into the schedule generated from the previous snapshot, thus an extended duration schedule is established. The new completion date is compared to that of the project prior to performing the snapshot in question. The difference between the two completion dates is the amount of delay that affected the project as a result of the delaying events which have occurred during the snapshot period. Once the time impact has been determined, the causes of delays are assessed.

Before starting the next snapshot analysis, the schedule has to be revised, if necessary, to reflect the planning of the project at that point in time under consideration. When the revisions are done, the difference in the project completion date of the extended duration and the revised extended duration schedules is an indication of the amount of acceleration (or relaxation) achieved through change in planning. The revised extended duration schedule now becomes the baseline schedule for the next snapshot analysis.

The snapshot technique starts with the as-planned schedule and the delay analysis is progressively performed for each determined snapshot period. The total delay is calculated by summing up all the delays associated with each time period, disregarding any time gained through acceleration. The measurement of the time impact is inclusive of both direct and indirect consequences of a delay-causing event. The extended time is then analyzed for apportionment of responsibility between the owner and the contractor. The total delay time is not necessarily the basis to qualify damages. The extent of acceleration costs should also be considered (Tardif 1988).

2.4.6 Time Impact technique

The time impact technique, is similar to the snapshot technique in examining the effects of delays at different times in the project. But the difference is that the time impact technique focuses on a specific delay and not at a time period containing delays. The idea is to obtain a "stop-action" picture of the project before and/or after encountering a major impact on the schedule (Leary et al. 1988). The as-planned schedule is first verified to reflect the contractor's actual plan, and second, it must be updated at certain critical periods in the construction process, thereafter the actual duration of the project is established. The delav is inserted into the schedule, the project duration is recalculated, and a new project completion date is determined. The difference between the two completion dates is the effect that the delay had on the project at the time it was inserted into the schedule.

This technique is progressively applied for each delay or delaying event which is to be analyzed. In order to obtain an accurate impact upon the overall project completion date, the schedule should be updated with actual dates and durations prior to incorporating the analyzed delay. This ensures that critical paths are accurate at the time of the delay is being analyzed. By adding all the individual time impact analyses, a total impact of delays on the project completion date is determined. This amount of total delays is then analyzed for apportionment between the owner and the contractor (Leary et al. 1988).

2.4.7 Isolated Delay Type technique

In performing the isolated delay type technique (Mazerolle et al. 1993), which applies only the relevant portion of the delays in the time period, within an as-planned schedule. Comparing the project's completion date before and after inserting the delaying events may generate a change in the project's completion date. This discrepancy is attributed to the delay that was incorporated into the schedule. When applying this technique from the contractor's point of view, excusable compensable and excusable noncompensable delays are incorporated in the schedule in order to calculate an adjusted schedule. This schedule is compared against the previous one and the variance is the amount of time the contractor was justifiably delayed. However to find the amount of time the contractor can seek compensation, only excusable delays are incorporated in the schedule and the difference between the two completion dates is calculated. Conversely, the owner can use this technique to measure the amount of time that he is entitled to liquidated damages from the contractor. The nonexcusable delays would be incorporated to determine a new adjusted schedule, thus the discrepancy between the two schedules would be the amount of time to quantify the liquidated damages (Mazerolle et al. 1993).

2.4.8 Concurrent delays analysis technique

This method provides a way for dealing with concurrent delays (Kraiem et al. 1987). Delays are identified on the as-built schedule according to their types, including the adjustments necessitated for concurrent delays. This adjustment consists of allocating a different code to these concurrent delays that identifies the type of concurrency. A series of adjusted schedules are calculated by excluding the considered delays from the as-built schedule for each type of delays to determine the time variance due to the relevant delays (Kraiem et al. 1987).

2.5 Quantification of Costs in Delay Claims

In all construction claims, there are two major issues which must be overcome; entitlement and quantification. Whenever entitlement for construction delay claims has been approved, there must be compensation. Since both the owner and the contractor are involved, two kinds of compensations are required, first the owner is entitled to liquidated damages when the contractor has been in fault for the delay, and this amount per day is determined from the contract language which has been previously agreed upon. Second when the owner is responsible for the delay, the contractor is entitled to time extension and to additional costs due to compensable delays, including direct, indirect, overhead, and impact costs.

2.5.1 Costs of Contractor's fault delays

The inclusion of a liquidated-damage clause in a construction contract has been said to be "the contractors' enemy" (Simon 1979). The liquidated-damage provision is generally deemed to be instead of actual damages for delays due to the contractor. If there is no liquidated-damage provision, the contractor is liable for the actual damages caused by his delays.

Most construction contracts contain a provision for liquidated damages (Rubin et al. 1983). Such clauses amount to a charge against the contractor for not completing the work within the time specified in the contract. The great advantage of liquidated damages is that the amount is set beforehand, and that both parties know exactly what a day of delay in completion of a job will cost, assuming the contractor is at fault. It is not necessary to calculate actual damages. In many cases where actual damages would be difficult to prove, this is an expedient method for the owner to recover those damages arising from contractor's delay. The courts have held that liquidated damages may not be used as a penalty. Where the damages figure has been proven to be a penalty against the contractor, the courts have held these unenforceable (Rubin et al. 1983).

Liquidated damages are, or can be, an effective tool in construction. They are calculated when the number of nonexcusable delays is determined from a delay analysis technique. The problem associated with liquidated damages is one of fixing on a reasonable figure. In the absence of a liquidated damages clause, the contractor will be liable for the owner's proven actual damages due to unexcused late completion. The following are some considerations for the owner to establish the liquidated damages (Rubin et al. 1983):

1. Extra rental of other buildings that might be required because the one being built is not completed.
2. Extra maintenance and utility costs that may be incurred either in the continued use of old high cost buildings or equipment or in the maintenance of a new area before beneficial use.
3. Interest on the investment or borrowed capital.
4. Extra training required to maintain worker skills pending availability of the building or equipment.
5. Extended supervision cost.
6. Additional operating costs that may result from the continued use of inefficient facility or equipment.

7. Extra costs of split operations resulting from partial occupancy or use of equipment.

8. Loss of revenue, building rentals, etc.

9. Impact costs relating to follow-on contracts (Rubin et al. 1983).

10. Loss of warranties (O'Brien 1980).

2.5.2 Costs of Owner's fault delays

The best measure for costs is dollar value. A cumulative change of 5% of base value is normal; a cardinal change would be in excess of 10% (O'Brien 1980). Costs due to delays caused by the owner or compensable delays, can be categorized in two major types: the direct, the indirect, and the overhead costs on one hand; and the impact costs on the other hand.

i) Direct, Indirect, and Overhead costs

Direct costs are directly related to the construction activity, while indirect costs are indirectly related to the affected activity. Overhead costs are the portion of costs that cannot be associated with particular operations, and are of two types: office and job. All these costs are calculated when the compensable delays are identified (Hohns 1979, Ostwald 1992). Most of the relevant costs considered in a claim analysis are listed as follows (Walstad et al. 1980a):

1. Labour

   . Extra labour

   . Labour escalations

   . Extended payments for workmen compensation, and other insurance benefits

. Employee taxes

2. Material

   . Extra materials

   . Reasonable estimate for breakage

   . Materials escalation

   . Transportation costs

3. Equipment

   . Extra equipment

   . Extended equipment use

   . Cost of idle equipment

   . Allocation of depreciation expenses and repair costs

   . Actual cost of leased equipment

   . Equipment insurance

4. Supplies

   . Extra supplies

   . Increased "general conditions" costs

   . Small tools

   . Field office supplies

   . Replacement costs

   . Storage

5. Supervision

   . Extra supervisory personnel

   . Extended supervision

. Increased salaries and related benefits

6. Field Office Overhead

   . Added field office costs

   . Extended field office overhead

   . Utilities

   . Weather protection

   . Office supplies

   . Leased space

   . Field office trailer

   . Temporary heat, light and water

   . Insurance

7. Home Office Overhead (General and Administrative Expenses)

   . Excess overhead expense

   . Extended home office overhead

8. Financing Expenses

   . Interest on retainage

   . Excess interest paid because of unapproved change orders

9. Extended Builders Risk Insurance Coverage

10. Additional Bond Costs

11. Lost Profits, and others, (Walstad et al 1980).

ii) Impact costs

Impact costs are generally defined as the increased costs of one or several related construction activities, in excess of what those costs would have been except for an incident, action or omission relating to a separate (discrete) item of work (Brunies 1988). Impact costs, or ripple effects as they are often referred to, originate in one or more isolated problems and may spread all through a project. Some authors refer to impact costs as disruption costs, loss of productivity costs (Dieterle et al. 1992), or less often loss of labour output (Brunies 1988). Impact costs may be broadly classified under two categories: time-related, and productivity-related (Dieterle et al. 1992).

Time-related costs are those associated mainly with extended duration, i.e. extension of the project beyond the original contractual completion date. Once the time extension entitled to the contractor for compensable delays, has been established quantification of time-related costs is a relatively simple exercise (Hohns 1979). Productivity-related costs are those resulting from productivity losses or reduction. Those costs can rarely be estimated accurately, simply because it is difficult to prove what costs would have been incurred without the inefficiency or without the causes being considered (Moselhi et al. 1990). In computing the costs of inefficiency, percentages of loss of productivity are often used.

2.6 Existing Methods for Quantifying Impact Costs

Several methods and their variations have been suggested in literature to evaluate the loss of productivity and consequently the impact costs. These methods may be grouped under three main categories: the Total Cost method, the Differential Cost approach, and the Statistics Estimating.

2.6.1 Total Cost Method

Contractors prefer this method of quantification, since the actual costs incurred are subtracted from what had been estimated or bid, plus approved change orders (Dieterle et al. 1992). It does not even relate between the reason for entitlement and the quantity of the corresponding loss (Brunies 1988). This method can be used for any category of direct costs; however it is most often used to calculate damages related to labour. The courts have limited acceptability of the total cost method only when the following prerequisites have been met (Dieterle et al. 1992):

. The nature of the particular loss makes it impossible or highly impractical to determine them with a reasonable degree of accuracy.

. The contractor's bid or estimate was realistic.

. The actual costs were reasonable.

. The contractor was not responsible for the added expenses, that is, the contractor performance was reasonably efficient.

In spite of some acceptance, this method should be used only as a last resort when no other feasible method is applicable (Dieterle et al. 1992).

2.6.2 Modified Total Cost Approach

This method is similar to the total cost method, but it differs in that the contractor makes certain adjustments to his bid estimate to account for inaccuracies in the bid, or to deduct amounts from actual costs for which the owner is not responsible. This in effect results in a net cost overrun, thus adding credibility to the claim (Dieterle et al. 1992).

2.6.3 Differential Cost Method

This method is the most preferred by courts, since it provides the calculations that compare productivity units during impacted and non-impacted time periods. This method is also referred to as the cause and effect method, thus documentation and substantiation are vital in determining the amount of damages and proving the loss incurred (Dieterle et al. 1992). However, for the differential method to be acceptable, it is necessary to demonstrate that (Brunies 1988):

. The unaffected items, which have the normal productivity, are representative both in complexity and method of execution of the items which were impacted by the cause(s) under examination.

. The difference between the actual productivity (or cost) of the impacted items and the normal productivity (or cost) resulted only from the cause(s) under examination.

. All items analyzed must have been impacted by the cause in question.

. The normal productivity (or cost) of the unaffected items is supportable and is valid; it allows for all applicable risks and/or inherent shortcomings of the contractor, and represents a sufficiently large percentage of the item(s) of the work under examination to generate reasonable confidence in the comparison.

This method is to be performed after the fact and requires an amount of investigation in order to conclude that the guidelines are satisfied (Brunies 1988). However if the four qualifications are satisfied, the differential method is highly recommended for quantifying productivity loss as it takes into consideration the contractor's capability or inherent shortcomings. Consequently, the calculation is founded on demonstrated ability and not on the estimate (Jergeas et al. 1993).

2.6.4 Measured Mile Approach

This method of inefficiency computation is based on an extrapolation of actual workhours expended. Similar to the differential method it requires a period of unhindered time in which the labour productivity reflects an efficient use for that type of work. With this efficient time and the percentage of work accomplished and the related actual workhours, a theoretical estimate of the total efficient workhours required for completion of that type of work, on that project, can be derived. By comparing this projected workhour estimate to the total actual workhours expended and the budget estimate workhours allows for a judgement as to the probable accuracy of total labour estimate and the efficient or inefficient use of those workhours (Dieterle et al. 1992). The only data needed for this method are, a monthly summary of the actual percent complete (or quantity installed) and the actual labour hours for each class of work to be investigated, as well as the labour budget hour estimate for the project. The percentages are often available from the progress payment procedure. The budget estimate would, of course, be the contractor's bid estimate (Zink 1986).

2.6.5 Revenue per Workhour Approach

Another method for identifying productivity trends is the revenue per workhour approach. This method compares the revenues earned for each labour workhour consumed during various time periods of the work. This method is often used with total revenues but is most effective if labour revenues can be isolated (Dieterle et al. 1992). Care is required, however, if significantly different work activities are performed that would result in fluctuations of revenues per workhour.

2.6.6 Factor Approach or Statistics Estimating

The use of statistical analysis is the most enlightened method of estimating, either to forecast the most likely losses under definable circumstances, or to quantify loss of productivity in retrospect in cases where the differential method is not practical (Brunies 1988). The factor approach is based on the application of lost efficiency percentages for various conditions such as, stacking of trades, beneficial occupancy, etc, to actual labour costs. Numerous trade organizations have developed these productivity factors to quantify the economic impact on contractors. The factor approach falls somewhere between the least preferred, the total cost, and the most preferred, the cause and effect or the differential methods (Dieterle et al. 1992). The factors used to determine the productivity loss, can be based on historical data, that is, rates of productivity achieved on other contracts for similar work under similar circumstances: research data, including time and motion studies or industry-wide studies; and expert opinion data, based on theory, judgement and experience (Dieterle et al. 1992).

Throughout the last 30 years, factors from statistical charts have been developed by contract industry sources. The most commonly used in construction claims include studies performed by the National Electrical Contractors Association (NECA 1969), and effect of weather (NECA 1974), the Business Roundtable (1980) for scheduled overtime, the Mechanical Contractors Association (MECA 1976), which has developed factors for estimated productivity losses caused by 16 circumstances, and the US Army Corps of Engineers (1979), which uses factors to estimate the effect of scheduled overtime, crowding, disruption, morale, and motivation.

Other specific studies and estimates have been reported in the literature (Taner 1981, Brunies 1988). "Mathews Curve" (Heather 1989) is a model to estimate impact costs. It was developed after making studies of industrial machinery, bearings, etc., and assessing the life of the equipment. A knowledge-based approach has been used to quantify impact costs (Nicholas 1989, Moselhi et al. 1990). In this approach, the productivity related impact costs were calculated at the activity level. A model to quantify productivity loss due to change orders occurring with one or two major causes of impact, such as acceleration, and inadequate coordination and scheduling has been developed (Leonard 1988, Leonard et al. 1988, Moselhi et al. 1991). The analysis was carried out on industrial and building projects, for electrical/mechanical contracts, and civil/architectural contracts.

Factors or statistical charts for loss of productivity are most often used when there is no so-called normal period, that is, one of unimpaired productivity, during the contract, and when there is lack of relevant information and records. The following is a checklist for determining the acceptability of productivity factors in a construction claim (Dieterle et al. 1992):

. No period of normal productivity for work being analyzed;

. Difficulty in maintaining detailed cost accounting records:

- size of contractor,

- cost of maintaining accurate job records,

- complexity of contract work, and

- nature of contract work;

. Corroborating testimony:

- link between factors and actual job experience,

- expert testimony on acceptability of factors, and

- expert testimony on reliability of factor data;

. Proper use of factors:

- mathematical application,

- modification by contractor's job experience, and

- application in accordance with published guidelines.

2.7 Conclusion

The types of construction delays affect the entitlement to each party, in terms of time, money or both. Several delay analysis techniques are used by practitioners in the industry in order to determine the time impact. These techniques require the utilization of various types of schedules. Once the time and the entitlement of delays are determined, costs of damages due to delays are quantified. Depending on who is seen responsible for the delays the entitlements can vary accordingly. They can be in the form of liquidated damages if the delay is nonexcusable. These are agreed upon in the contract, and estimate the amount of money per day that the owner is entitled to claim for. In case of compensable delays the contractor is entitled to claim for additional costs including: direct, indirect, overhead, and impact costs. Impact costs related to productivity loss are difficult to calculate accurately, however several methods and their variations have been described to evaluate those costs. In practice, these methods do not apply to most of the circumstances, or require specific conditions and information.

CHAPTER III

THE PROPOSED DELAY ANALYSIS TECHNIQUE

3.1 Introduction

Delays are the most common and costly problem encountered in construction projects. Time is money was never more true than on a job requiring large amounts of capital, labour, and materials. Contractors continue to absorb costs that would have been compensable if properly identified, documented and claimed. Several delay analysis techniques are currently utilized by practitioners, and they range from simple dates comparisons, to tedious and time consuming detailed analyses, any of which can yield a wide variety of results. Since the ultimate goal in preparing a delay analysis is to present accurate and credible results as supportive documents in a claim, which is the major step towards proving the effects of delays, it is necessary to ensure that the technique applied is persuasive. The objective of this chapter is to propose and discuss a new and effective delay analysis technique. For this purpose, it was essential to assess the different delay analysis techniques currently available in the industry, by applying each technique to a common test case, analyzing the results, and highlighting their shortcomings and advantages.

3.2 The Test Case

To better assess the existing delay analysis techniques, a case study has been adopted from literature, (Kraiem et al. 1987). The test case is suitable for the analysis since it is simple, while consisting of ten activities and two critical paths, it comprises all the diverse types of delays which are well laid out. The scheduling software used in the process is Primavera (Primavera 1991).

Fig. 3.1, shows the as-planned CPM schedule of the test case, which consists of ten activities split into three paths. For the assessment of the delay analysis techniques, the precedence diagram method (PDM) format was used for its simplicity in being handled by the scheduling software. The PDM schedule, representing the critical path method (CPM) schedule, is broken down into the following activities:

Activities 1, 3, 6 and 9; critical path.

Activities 2, 5, 8 and 10; critical path.

Activities 2, 4, and 7; non-critical path.

The project's as-planned duration is 23 days from the start to the completion (Fig. 3.1). The as-built schedule (Fig. 3.2) maintains the same activities and relationships but includes many delays throughout the schedule, extending the total project duration by 18 days to become 41 days. Fig. 3.3, shows the comparison between the as-built and the as-planned bar charts. The delays identified in this test case are categorized into three types; excusable noncompensable (EN), excusable compensable (EC), and nonexcusable (NE). Further classification is done later to analyze concurrent delays (Kraiem et al. 1987). The following is a breakdown of the delays according to their type and duration in days, within each activity:

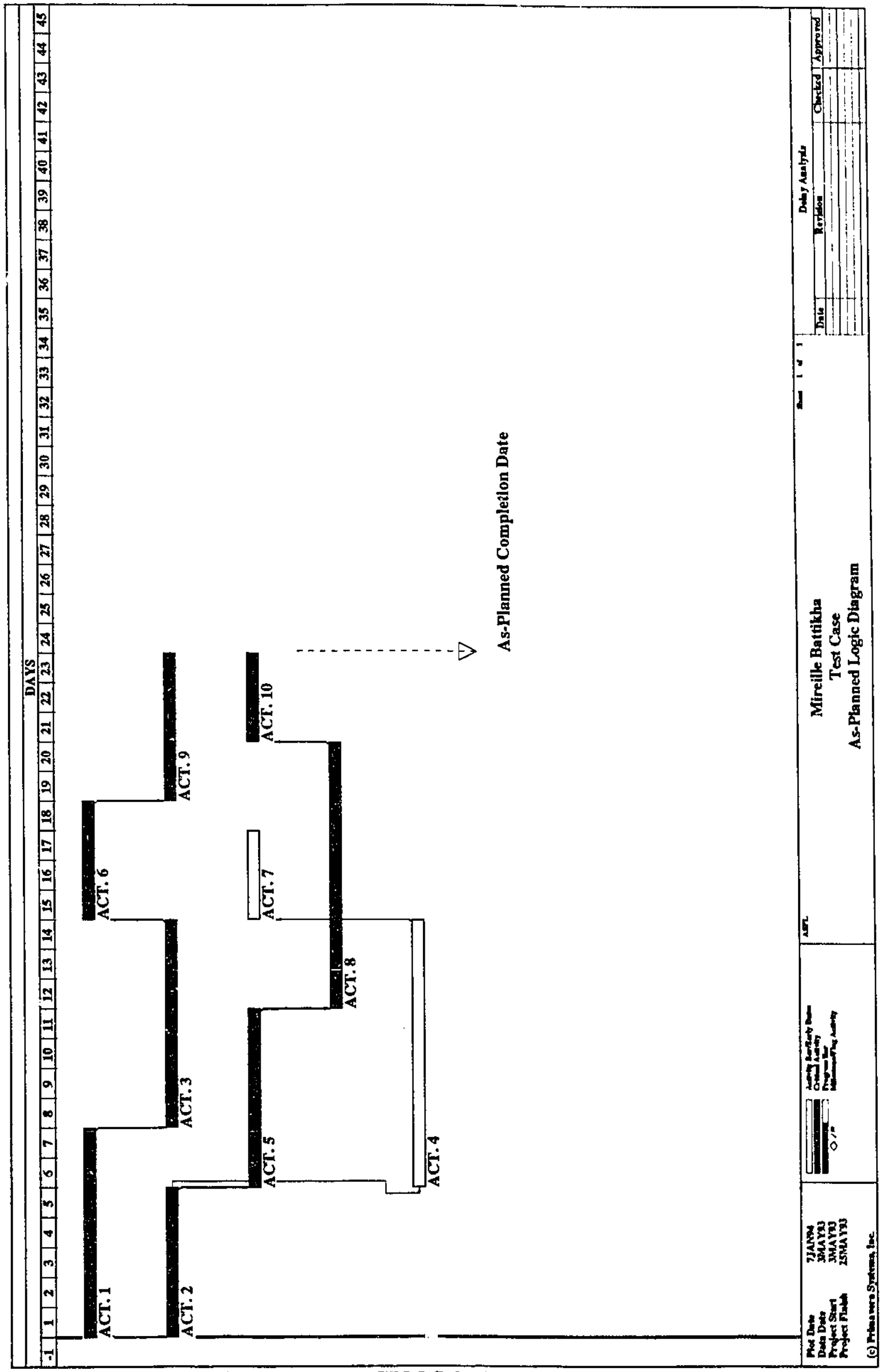

Fig. 3.1. As-Planned CPM Schedule; Test Case

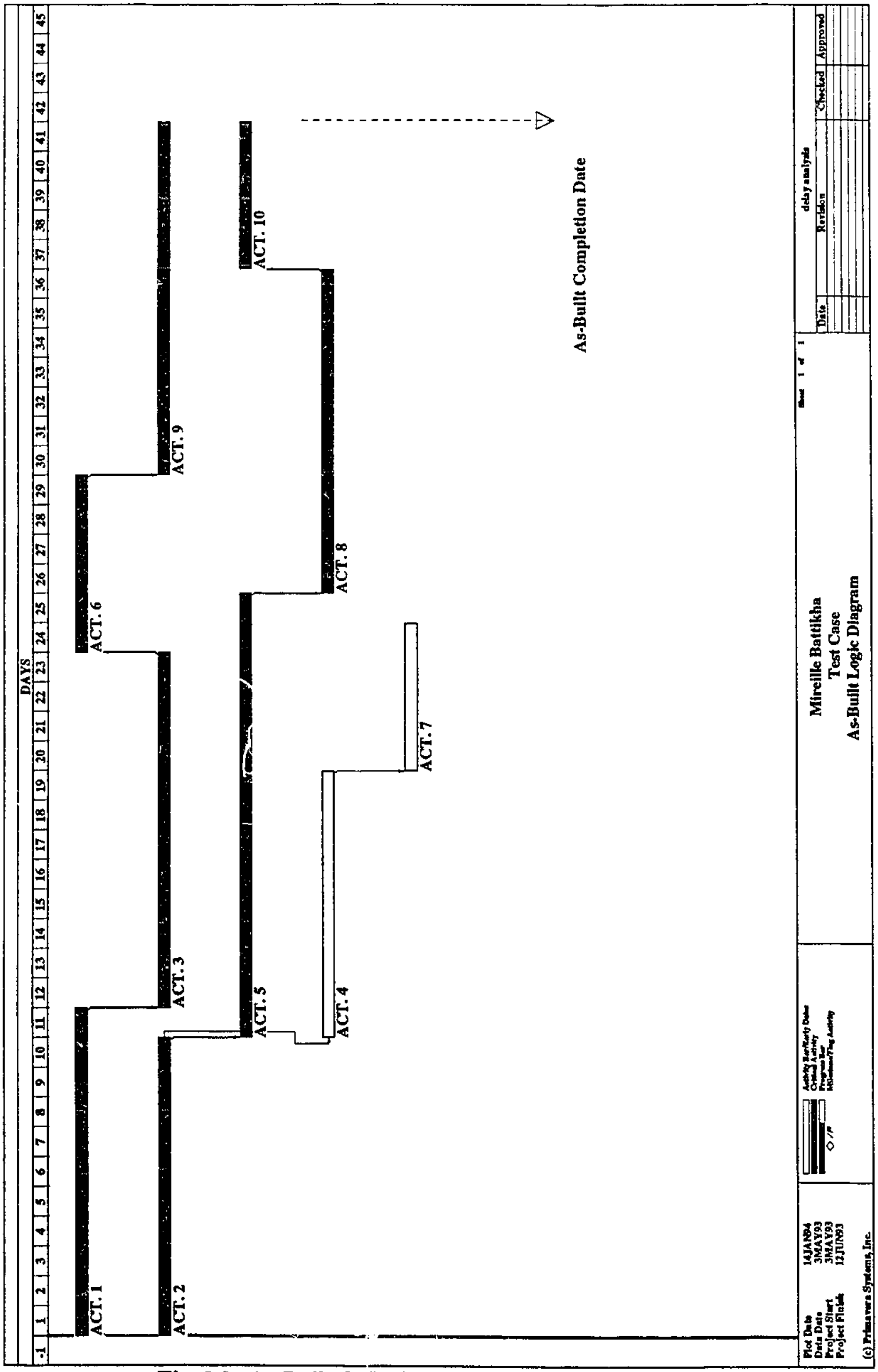

Fig. 3.2. As-Built CPM Schedule; Test Case

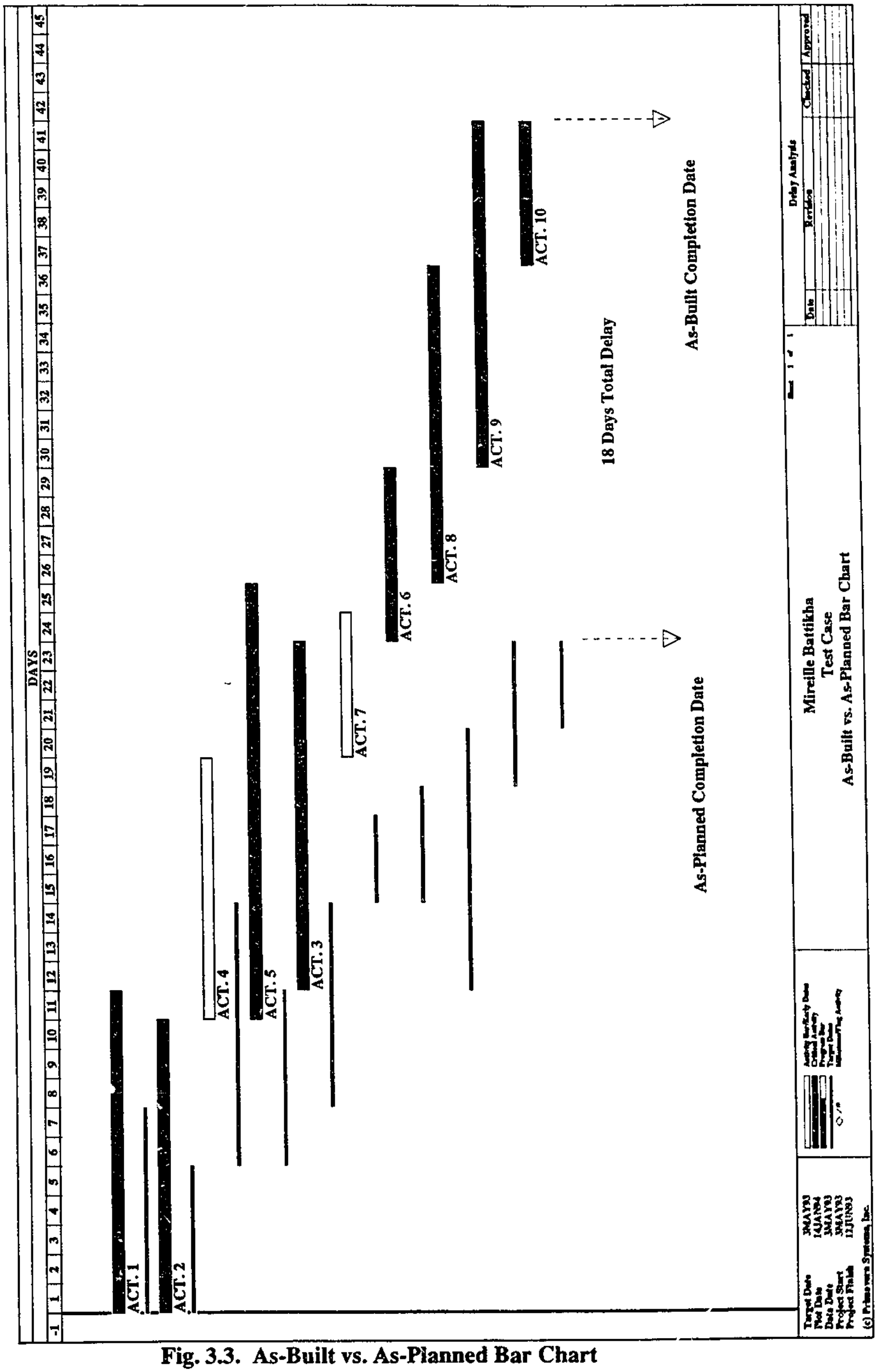

Fig. 3.3. As-Built vs. As-Planned Bar Chart

Activity 1: EN - 1, NE - 3;

Activity 2: EN - 3, NE - 1, EC - 1;

Activity 3: NE - 3, EC - 2;

Activity 4: -;

Activity 5: EN - 5, NE - 1, EC - 3;

Activity 6: EC - 2;

Activity 7: NE - 1, EC - 1;

Activity 8: EN - 1, EC - 1;

Activity 9: EN - 2, NE - 3, EC - 2;

Activity 10: EN - 2

3.3 Assessment of Existing Delay Analysis Techniques

The following delay analysis techniques were assessed using the test case:

- Global Impact
- Net Impact
- Adjusted As-Built CPM
- But For contractor's delays; owner's point of view
- But For owner's delays; contractor's point of view
- Snapshot
- Time Impact
- Isolated Delay Type; contractor's delays
- Isolated Delay Type; owner's delays
- Concurrent delays analysis

Starting with the same as-planned schedule, as-built schedule, and using the appropriate delays, each technique was applied to the same test case. The following sections contain descriptions of the delay analyses.

3.3.1 Global Impact analysis

To perform the global impact technique, the durations of all the delaying events identified in the test case were summed to determine the total delay to the project. Using a bar chart representing the as-planned and the as-built schedules as summary bars, as illustrated in Fig. 3.4, an additional summary bar showing the total delay in addition to the as-planned duration was simply included on the bar chart, to indicate the duration to which the contractor is entitled to accomplish the project. The total amount of compensable delays is 38 days which is the summation of all delays that occurred on the project, while the project completion date overrun was 18 days.

There are many problems with the global impact technique. The main issues that the global impact disregards, are: the effect of concurrent delays, and the classification of delay types, thus assuming that all delays have an impact on the project. Moreover even without concurrency the global impact assumes that any delay would have impacted the overall project completion date thus considering all activities to be critical. This frequently results in a contractor's claim for time extensions which extend well beyond the actual project completion date; the rationale is that the difference between the entitlement completion date and the as-built completion date is the amount of time saved by acceleration (Leary et al. 1988). While this technique is simplistic, it is inaccurate in

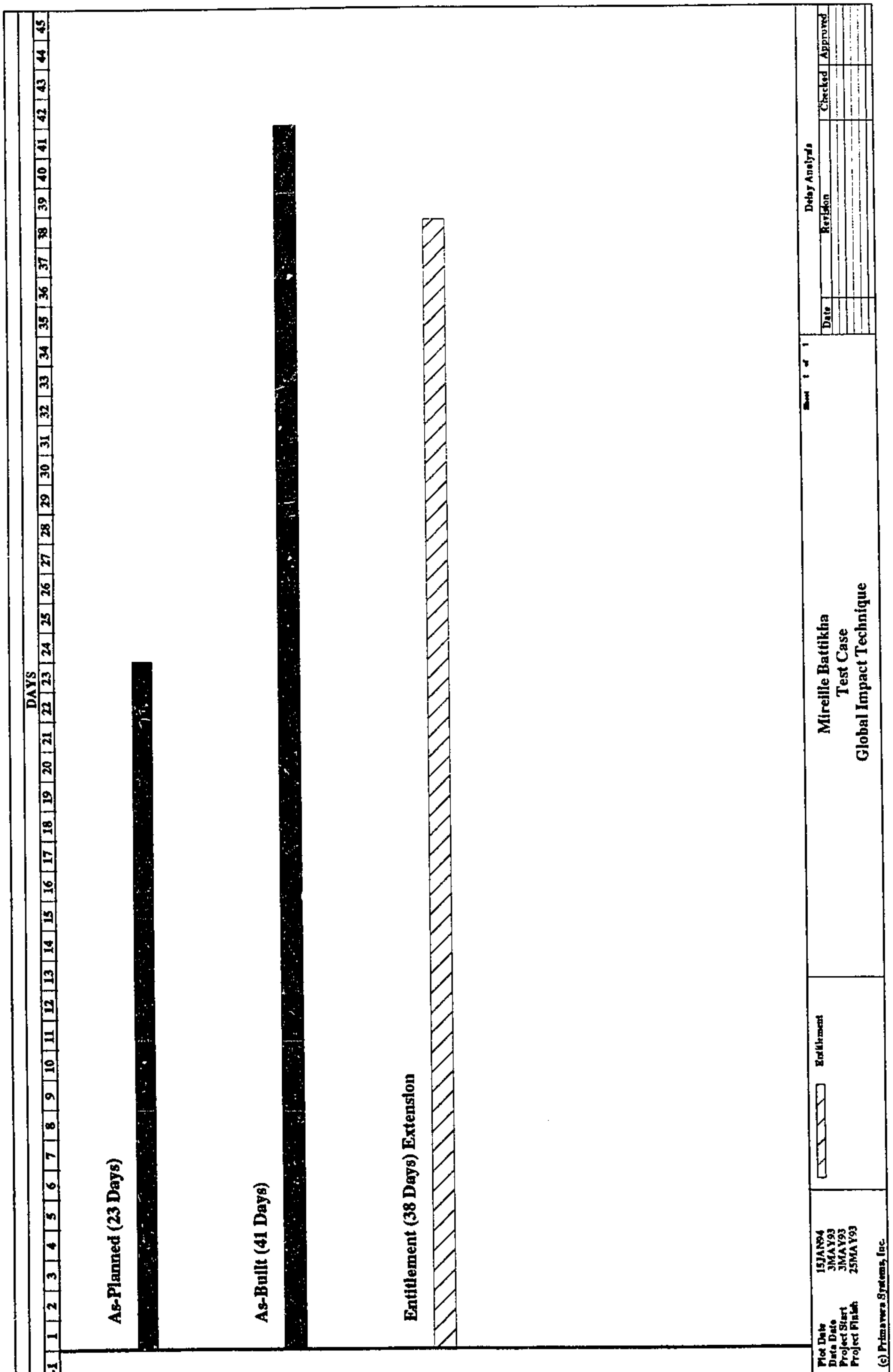

Fig. 3.4. Global Impact Technique

depicting the impact of delays. However, it is often used by claimants during the initial requests for time extensions.

3.3.2 Net Impact analysis

In order to avoid the problem of concurrency faced with in the global impact technique, claimants use another technique, called net impact technique. It depicts only the net effect of all delays on a bar chart. The time extension claimed for, is the period from the as-planned completion date to the actual completion date of the project.

In implementing the net impact technique, all delaying events in the test case were plotted on an as-built schedule, using an as-planned and an as-built bar chart, only the net impact of the delays was depicted, as shown in Fig. 3.5. The net impact in this case is 18 days which is the difference between the as-built and the as-planned completion date. It is argued that the combined overwhelming effect of delays impacted the project, rather than the duration of each individual delay.

Although the net impact technique avoids the problem of concurrency, it does not scrutinize the types of delays. This results in an overstated amount of time requested for the claiming party. Further, without the use of network analysis scheduling techniques, it would become inaccurate to calculate the impact on the overall project due to any delay (Leary et al. 1988).

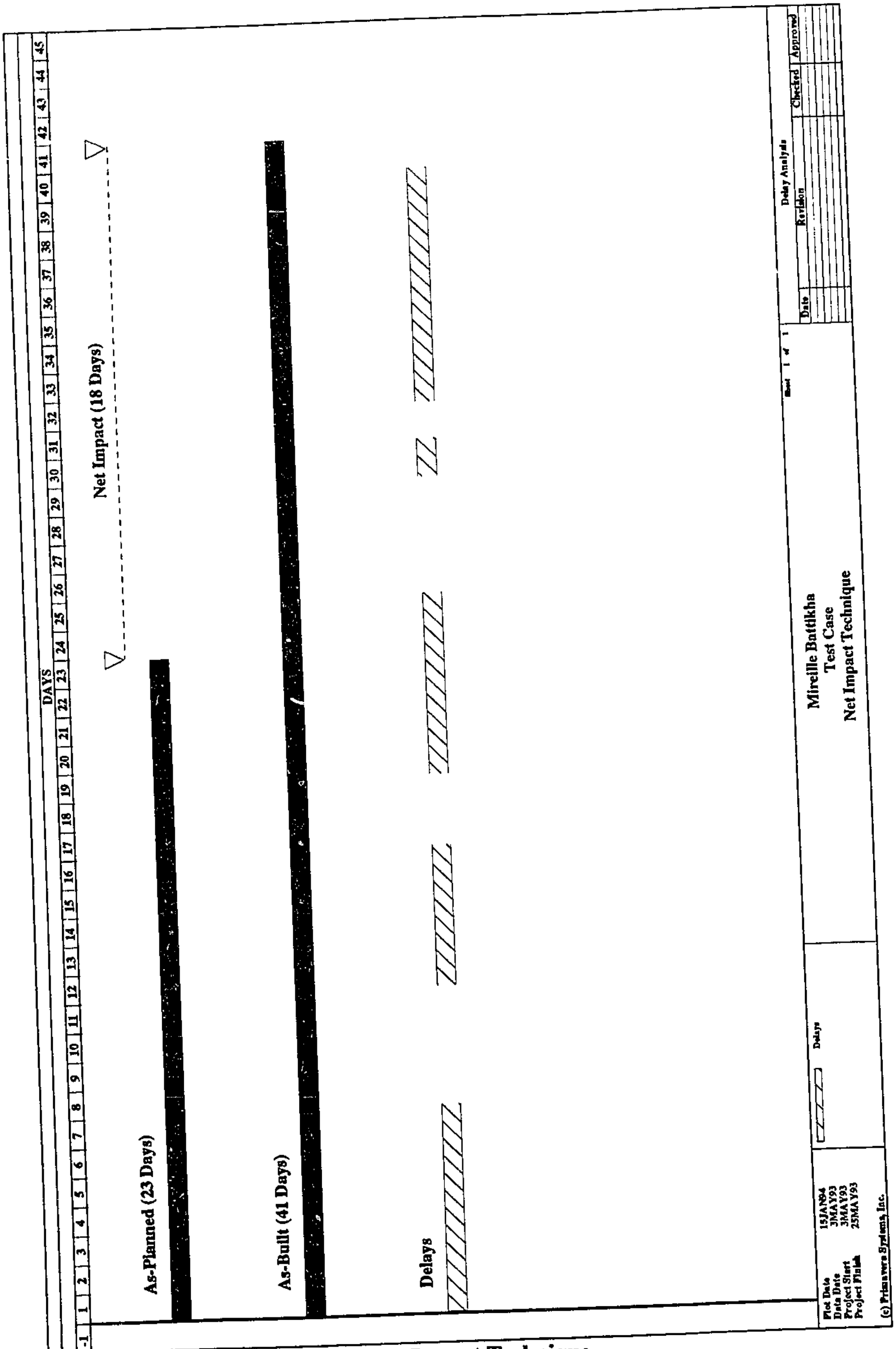

Fig. 3.5. Net Impact Technique

3.3.3 Adjusted As-Built CPM analysis

In applying this technique to the test case an adjusted as-built schedule for the entire project was developed, using the CPM format. All the delaying events were incorporated in the as-planned schedule, as independent activities which were tied to the original activities by restraints. Fig. 3.6 illustrates the CPM schedule generated from the application of the adjusted as-built CPM technique. A new critical path was established to the project. This critical path was calculated ounce after the fact and not at the time of the delay. Similar to the net impact this technique accounts for the net effect of delays, which is the difference between the 41 days adjusted completion and the 23 days of the as-planned completion duration resulting in 18 days for time extension.

Although the adjusted as-built CPM technique uses the CPM format which shows the inter-relationships between activities, this critical path is done after the fact and does not represent the real critical path at the time of the delay. Further, claimants could tie delays to the critical path, and the delays which are their responsibilities might be shown, but hidden in the schedule and not tied to the critical path (Leary et al. 1988). This technique is not much better than the net impact technique except that the CPM format gives a more sophisticated presentation, but still it does not scrutinize the types of delays and does not determine the individual impact of each delay on the project completion date.

3.3.4 But For (Collapse) analysis

The as-planned schedule was used as the starting point, and only the delays for which the claimant is willing to accept responsibility were incorporated in the schedule in order to

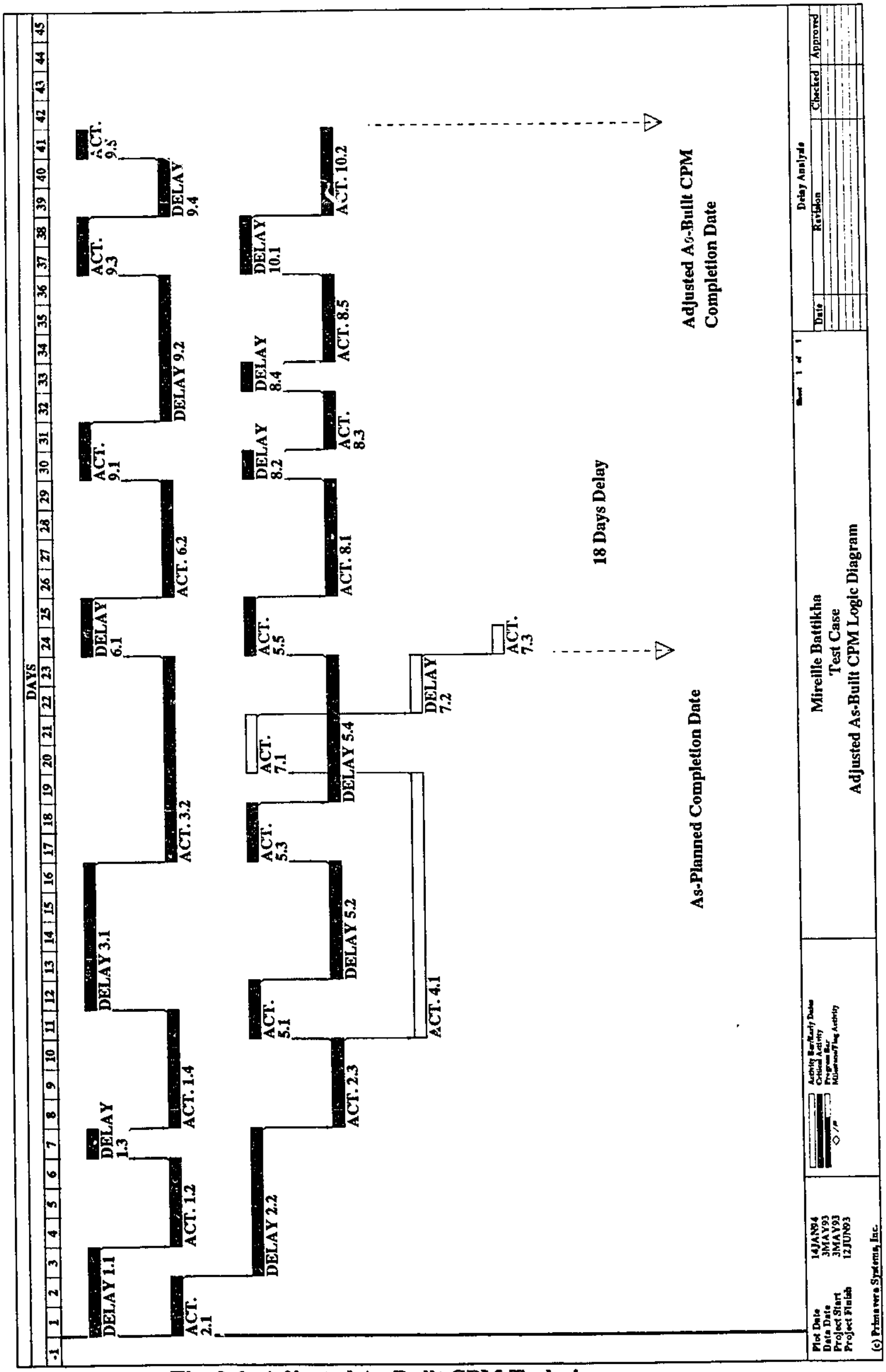

Fig. 3.6. Adjusted As-Built CPM Technique

recalculate the project completion date. The difference between the as-built completion date and the calculated completion date is the time for which the claimant is entitled to. The technique was applied from both the owner's, and the contractor's point of view.

i) But For Contractor's delays; Owner's point of view

In performing the but for contractor's delays, only the delays which the owner is responsible for, i.e. the excusable compensable and the excusable noncompensable were incorporated into the as-planned schedule to generate an adjusted completion date to the project, as shown in Fig. 3.7. As a result this adjusted duration of the test case became 39 days. This indicates that but for the contractor's delays the project would have been finished in 2 days less than the actual duration of 41 days. Thus, the contractor is responsible for 2 days delay for which the owner is entitled to compensation.

ii) But For Owner's delays; Contractor's point of view

Considering only the delays for which the contractor is responsible, i.e. nonexcusable delays were inserted into the as-planned schedule, as shown in Fig. 3.8. The adjusted completion duration of the project resulted in 32 days, which is less than the as-built duration of 41 days, by 9 days. This discrepancy represents the time extension that the contractor is entitled to request for.

The But For technique provides a better method for delay analysis, since it addresses the issue of concurrent delays, only those overlapping and due to the same party, and not the concurrent delays that are due to opposite parties. However, it does not analyze the

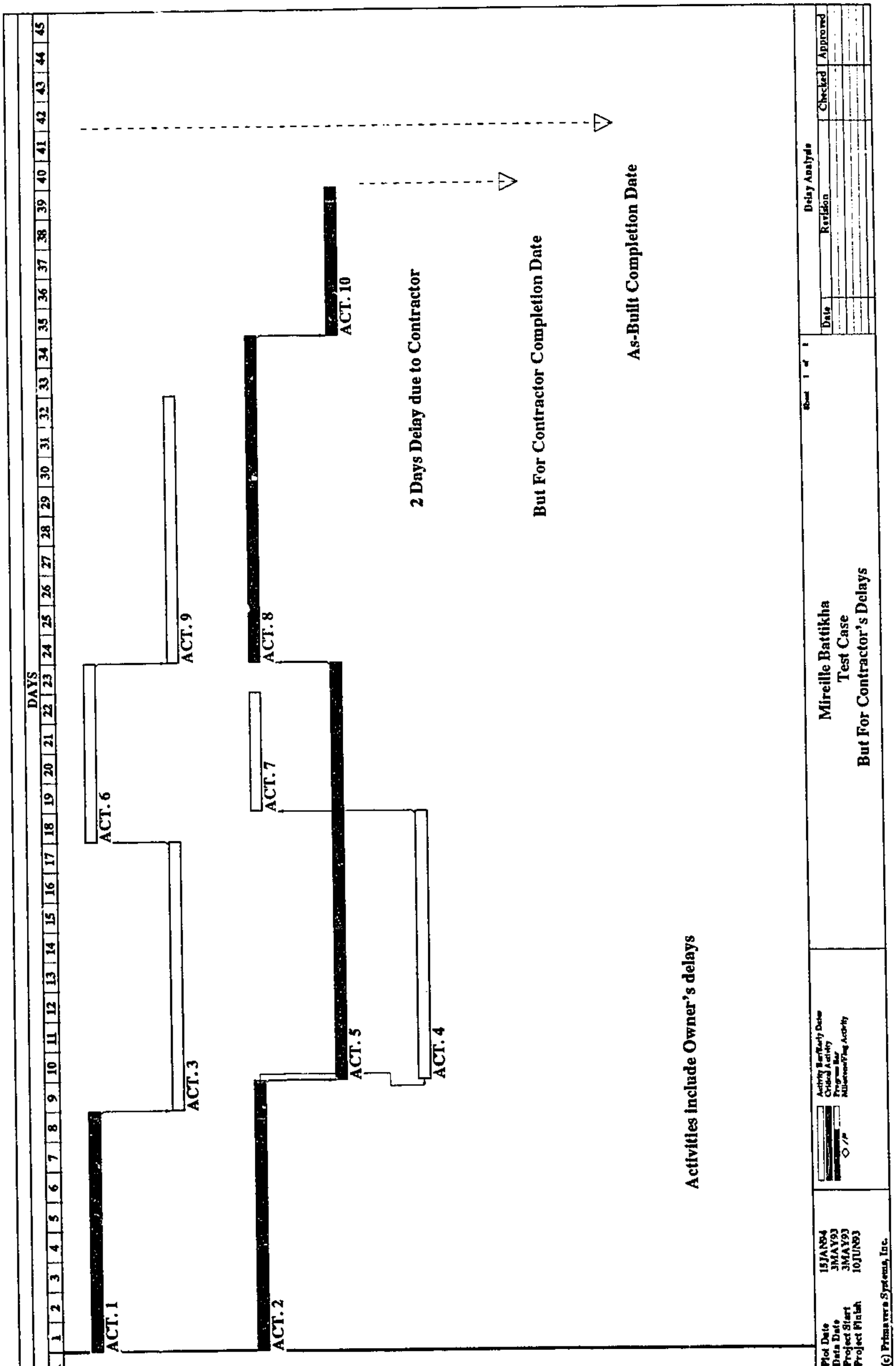

Fig. 3.7. But For Contractor's Delays Technique

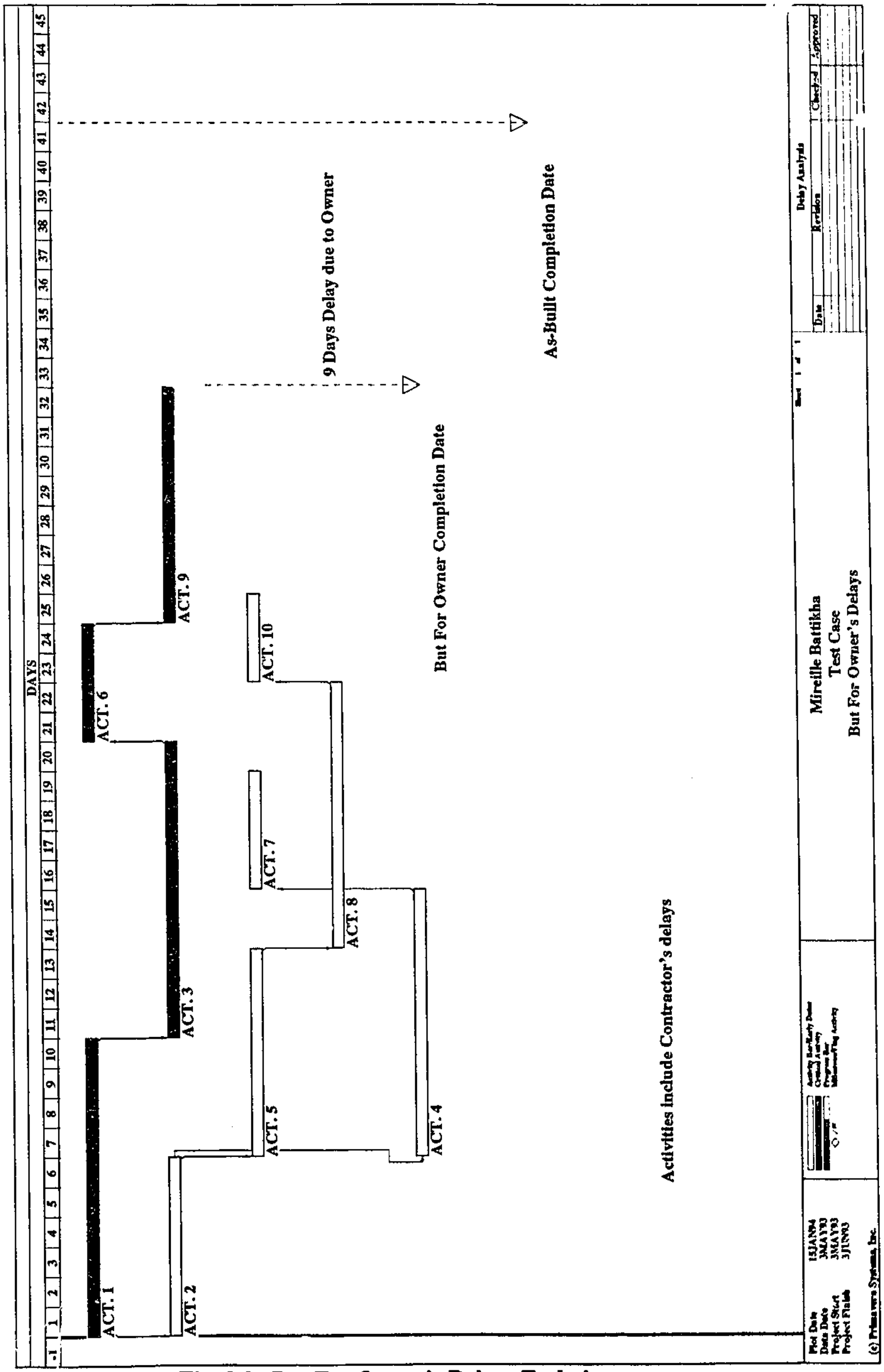

Fig. 3.8. But For Owner's Delays Technique

concurrent delays where an adjustment must be done to the types of delays, i.e. when a delay occurs at the same time with an excusable delay and both are on a critical path, they need to be analyzed differently for their entitlement (Rubin et al. 1983, Kraiem et al. 1987). Moreover, cause and effect relationships are not dealt with in the but for analysis, since delays are incorporated in one shot after the fact. In addition, the but for scrutinizes the types of delays and deals with the delays of each party independently, however this separation of analysis results in hypothetical critical paths that are out of context and time of the actual critical path when the delaying event occurred. The potential for inaccurate results lies in the fact that the critical path changes during the project and the delays which may be on the critical path of the actual schedule may not appear on the critical path of the adjusted schedule.

In the analysis done using the but for technique, the owner was found to be liable for 9 days, and the contractor for 2 days. Adding both parties' delays results in a total delay of 11 days. However the project was impacted by an overall duration of 18 days, which is the difference between the as-built duration of 41 days, and the as-planned duration of 23 days. Moreover, if the same analysis is done after performing the analysis and adjusting the concurrent delays that was described in the above discussion the results would change to 1 day delay due to the contractor (Fig. 3.9), and 12 days due to the owner (Fig. 3.10), resulting in 13 days total delay, which is still not equal to the 18 days total project delay. These days of difference between 11 and 13, are due to the overstatement of time due to overlapping delays from both parties for which an adjustment should have been performed. Since delays that are on critical paths and

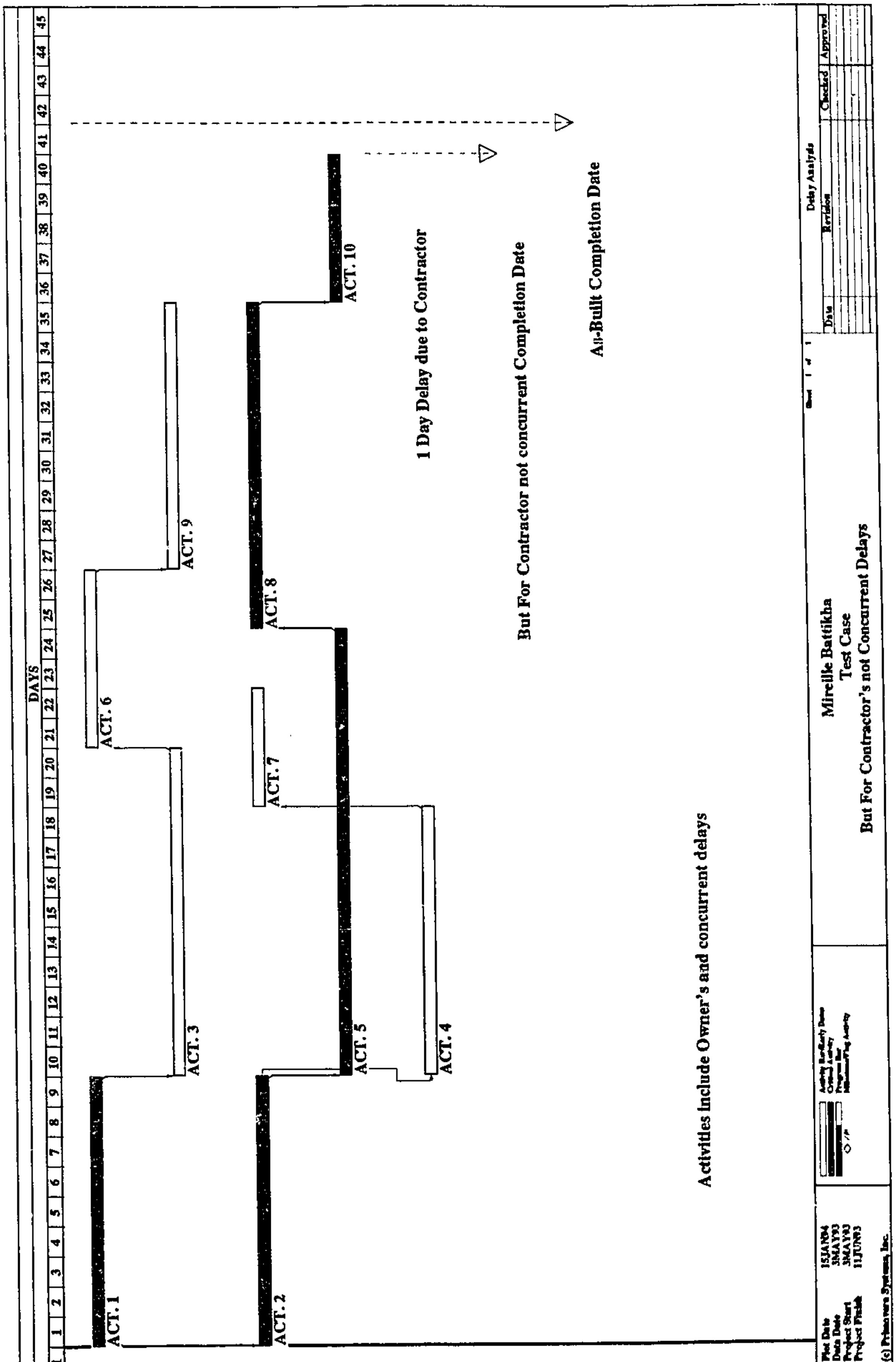

Fig. 3.9. But For Contractor's Not Concurrent Delays

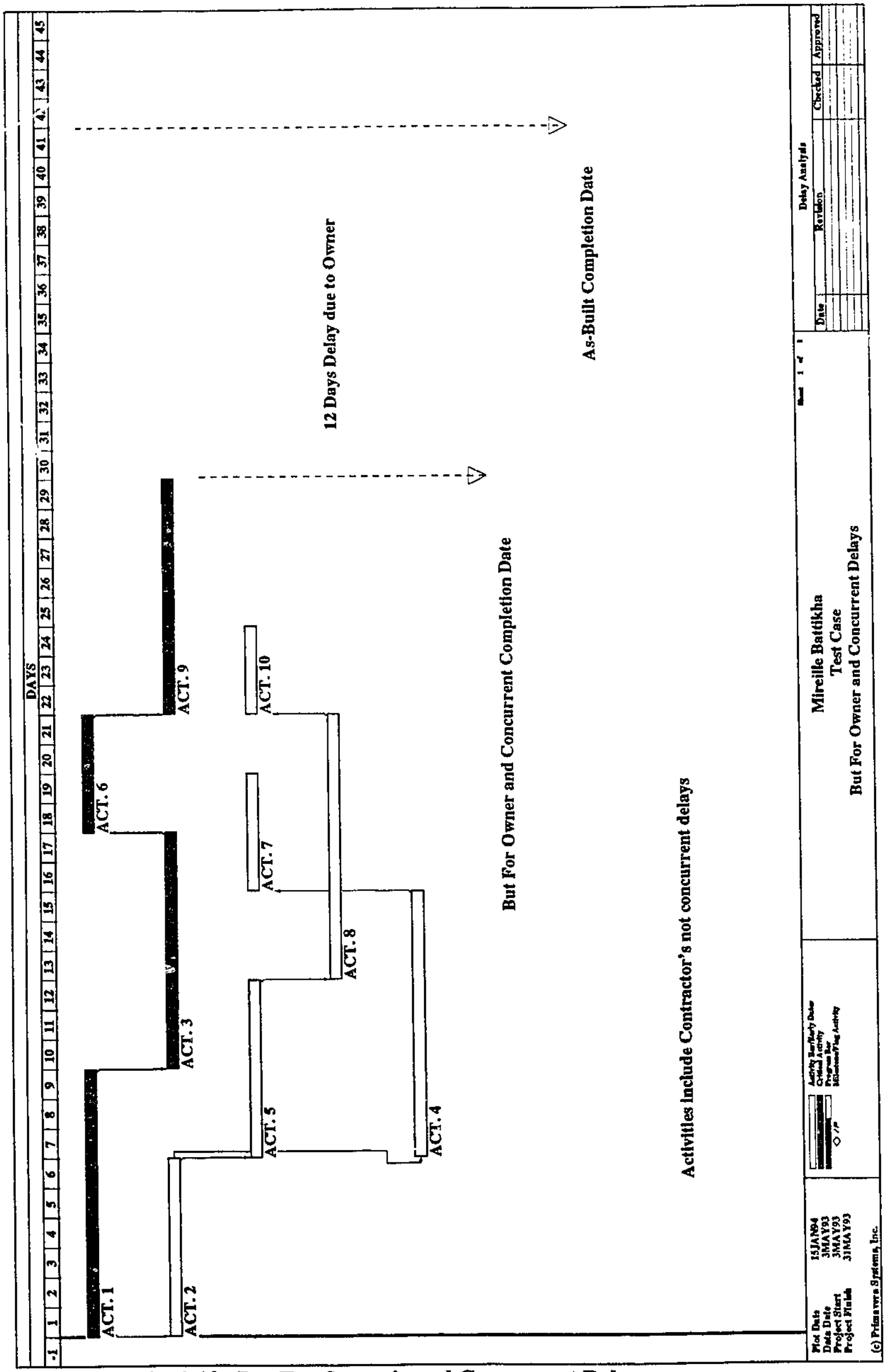

Fig. 3.10. But For Owner's and Concurrent Delays

concurrent with excusable delays will be considered as excusable noncompensable delays (Rubin et al. 1983, Kraiem et al. 1987). This step of adjusting concurrent delays is very important, and must be performed before starting the schedule impact analysis, in order to ensure that all delays are properly scrutinized and adjusted according to liability. However, the difference of the total project delay of 18 days, and the summation of both parties delays of 11 days or the 13 days is one of the main shortcomings of the but for technique, and considered as an understatement of total amount of delays.

3.3.5 Snapshot analysis

In order to perform the snapshot technique to determine the impact of delays on the project completion date, two snapshot periods were imposed on the test case in order to shorten the procedure, however the more periods one could provide, the more accurate results would be obtained. The first snapshot period, as shown in Fig. 3.11, was taken from the starting day till day 20 inclusive, where the day number is taken from the as-built schedule where all delays were identified in time duration. Performing the first snapshot analysis, the as-planned schedule was used to start and all delays that occurred during the snapshot in consideration were incorporated into that schedule. An as-built durations and logic of activities for the first snapshot period was established, while maintaining the rest of the schedule after that period as denoted in the as-planned schedule. The new project completion date was determined, and that adjusted duration of 34 days was compared to the as-planned duration of 23 days, resulting in a delay of 11 days due to the delaying events that occurred in the first snapshot period. This new schedule became the baseline schedule for the next snapshot analysis. Any alteration to

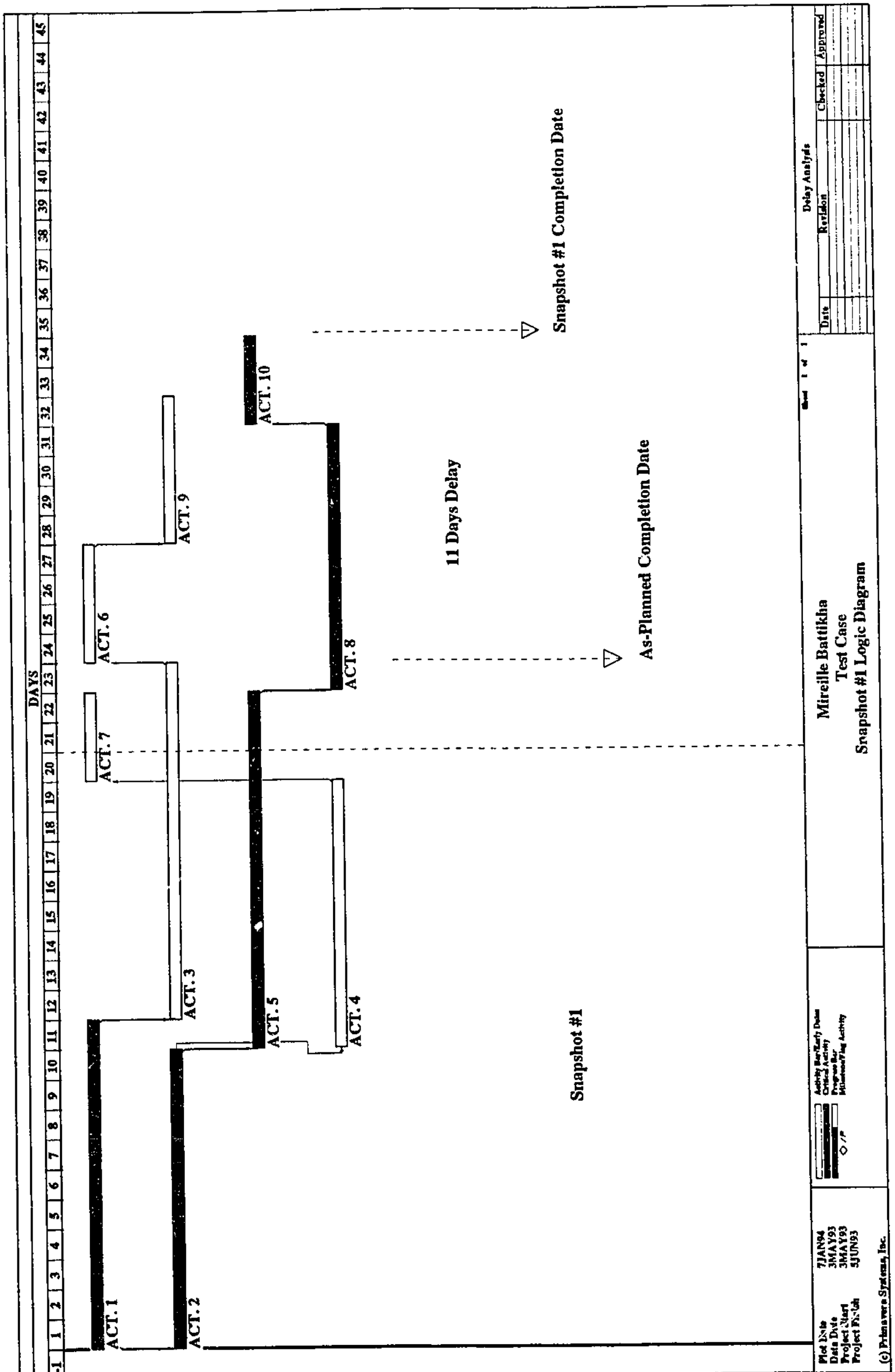

Fig. 3.11. Snapshot #1 Technique

the CPM must be included in the adjusted schedule before proceeding to the next analysis, however this step was not needed in this test case since no change occurred to the CPM.

For the second snapshot, that started from day 21 inclusive till day 41 or the end of project, the previous schedule of 34 days duration that was performed in the first snapshot was used as a base. Delays that occurred in the second snapshot period, were inserted into the schedule as illustrated in Fig. 3.12. The new completion duration of the project for this snapshot period was 41 days, that is a delay of 7 days, by comparing 41 days to 34 days of the baseline schedule. In every snapshot period the comparison was done with the schedule determined in the previous snapshot period analysis.

To obtain the total overrun of the project duration, a summation of all the delays determined in each snapshot is required, that is adding 11 days and 7 days to get 18 days of total delay, which represents the total extended duration of the project. This amount of delay is then apportioned after an analysis in order to determine the responsibility of each of the contractor and the owner.

The snapshot analysis offers some advantages over the other methods in the way it progresses with the schedule, since snapshots could be done as much as it is needed and a follow up of delays is performed thus a real critical path is determined at the time of the delay, thus taking into account the real effect of delays in time and context. This systematic and objective technique deals with problem of concurrency, and its accuracy

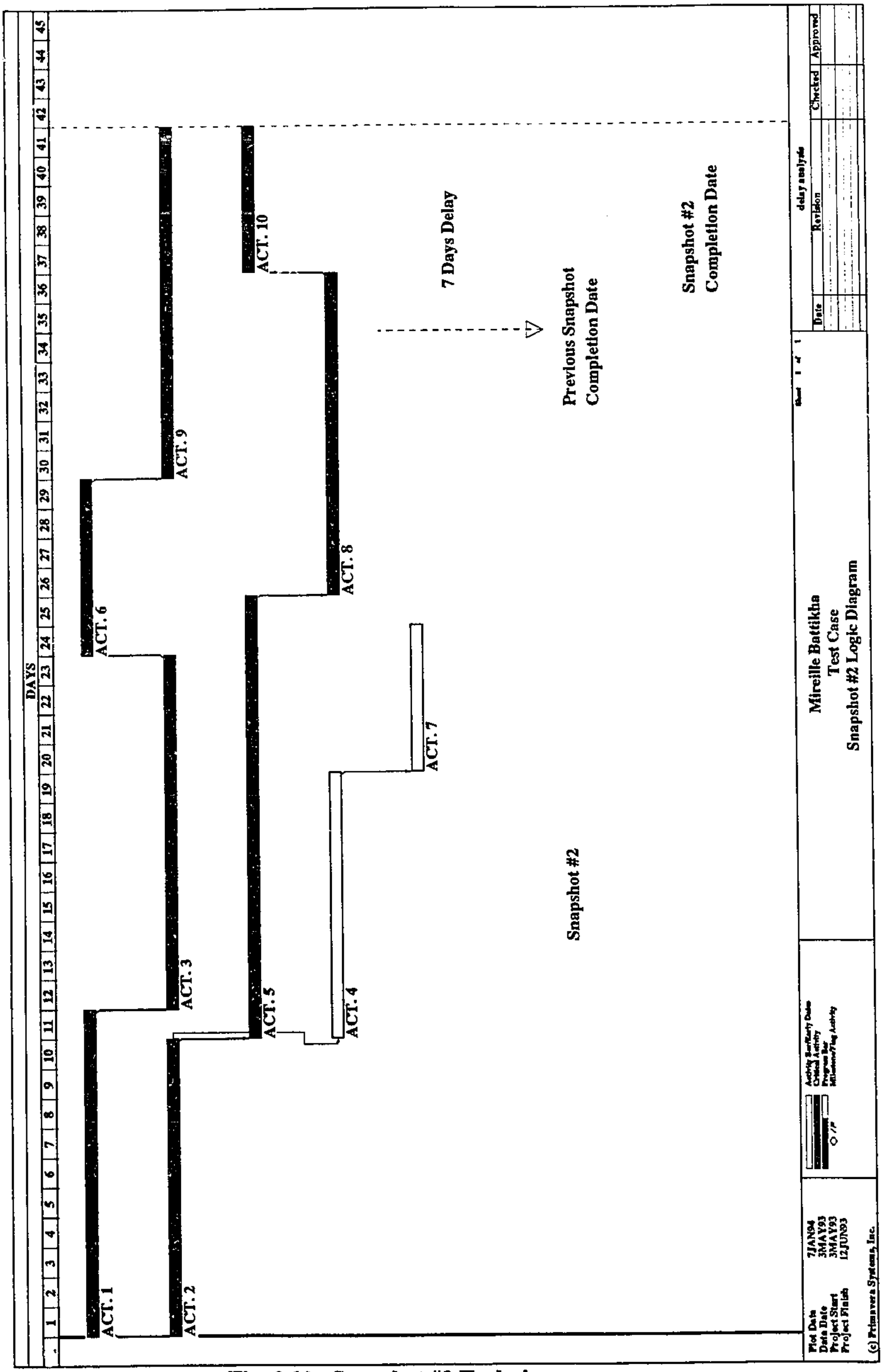

Fig. 3.12. Snapshot #2 Technique

depends on the number of snapshots performed, however it does not scrutinize the types of delays prior to the analysis, therefore, the results obtained require further complicated analysis to apportion the liabilities.

3.3.6 Time Impact analysis

The time impact is another way of examining periodically the effect of delays on the project. The analysis must be done to determine the effect that each delay had upon the schedule. The as-planned schedule should be updated at each major event or critical periods. In the test case under consideration delays were taken in each activity separately that is to say each delayed activity had been delayed by one major event. The stop actions were chosen at the start of each activity and the delay was incorporated in that activity after which an adjusted schedule was determined and compared to the actual schedule frozen prior to the start of the activity in consideration. Fig. 3.13 represents the first time impact analysis. Starting with the as-planned schedule the first delayed activity was inserted into the schedule with its actual duration, and a new project duration was determined. The difference of time between this adjusted duration and the previous as-planned duration of 4 days is the delay due to the impact that occurred in activity 1.

The actual duration of activity 2, was incorporated into the as-planned schedule, for the second time impact analysis. After recalculation, the project completion date was extended by 5 days, as shown in Fig. 3.14. The next activity to be analyzed was activity 3. Before inserting the actual duration of activity 3, the as-planned schedule was revised to reflect the actual schedule prior to the start of activity 3. A revised schedule was recalculated to

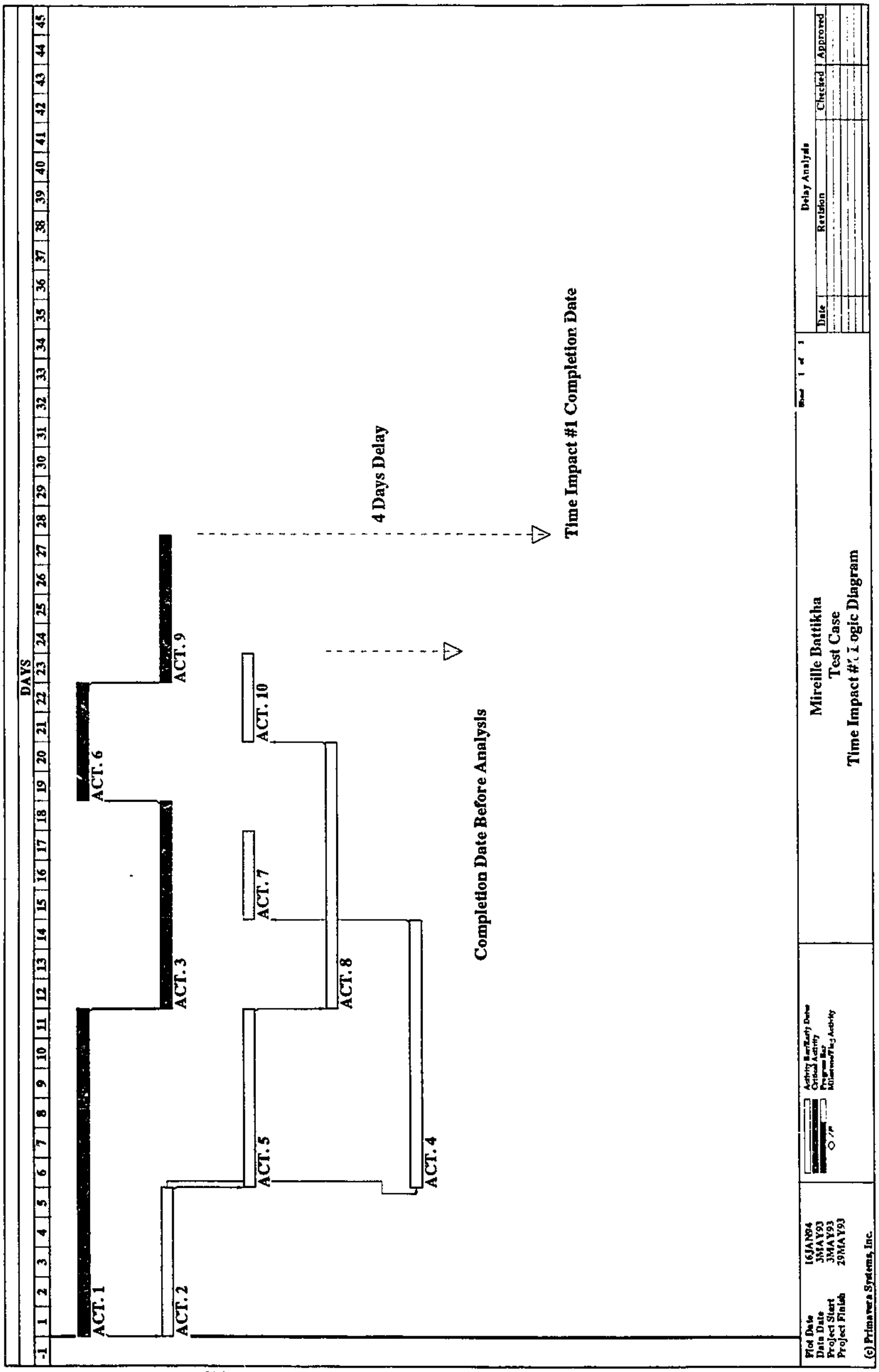

Fig. 3.13. Time Impact #1 Technique

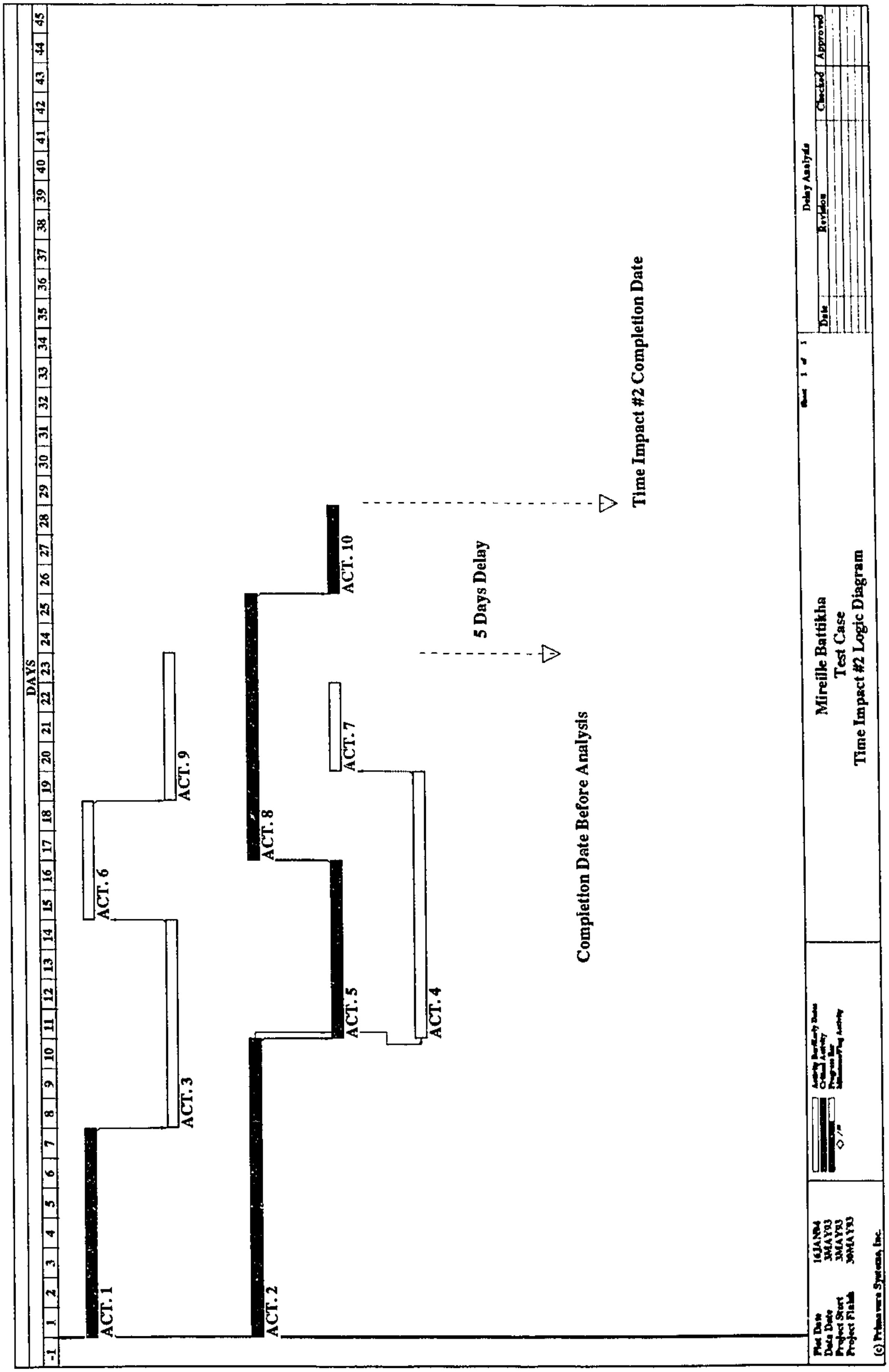

Fig. 3.14. Time Impact #2 Technique

determine the project's completion date. Then the actual duration of activity 3 was implemented in this revised schedule to determine an adjusted completion date, and the difference between the adjusted and the revised completion dates of 4 days, represents the amount of time the project had been delayed in accordance with the third time impact analysis, shown in Fig. 3.15.

The same procedure was applied to activities 5, 6, 7, 8, 9, and 10 (Fig. 3.16, Fig. 3.17, Fig. 3.18, Fig. 3.19, Fig. 3.20, and Fig. 3.21 respectively), and that resulted in delays of 9, 0, 0, 2, 4, and 2 days, respectively. Summing up all the delays determined in the nine analyses, a total of 30 days was obtained. This total amount of delay represents the total extended duration of the project, which should be further analyzed for apportionment of responsibility between the owner and the contractor.

The time impact technique provides a systematic and objective method of quantifying the impact of delays upon the project completion date, since it analyzes the effect of delays in their context of time and critical path status. The goal of this technique is to measure the actual impact of delays on the project, individually or combined, and even with ongoing projects. However this may become too cumbersome when there are an overwhelming amount of delaying events. In addition, since each delay is analyzed individually, the effect of concurrency is disregarded which results in an overstated amount of time extension to the overall project completion. Moreover, this technique does not scrutinize the types of delays prior to the analysis, therefore, further analysis is required for the apportionment of responsibilities.

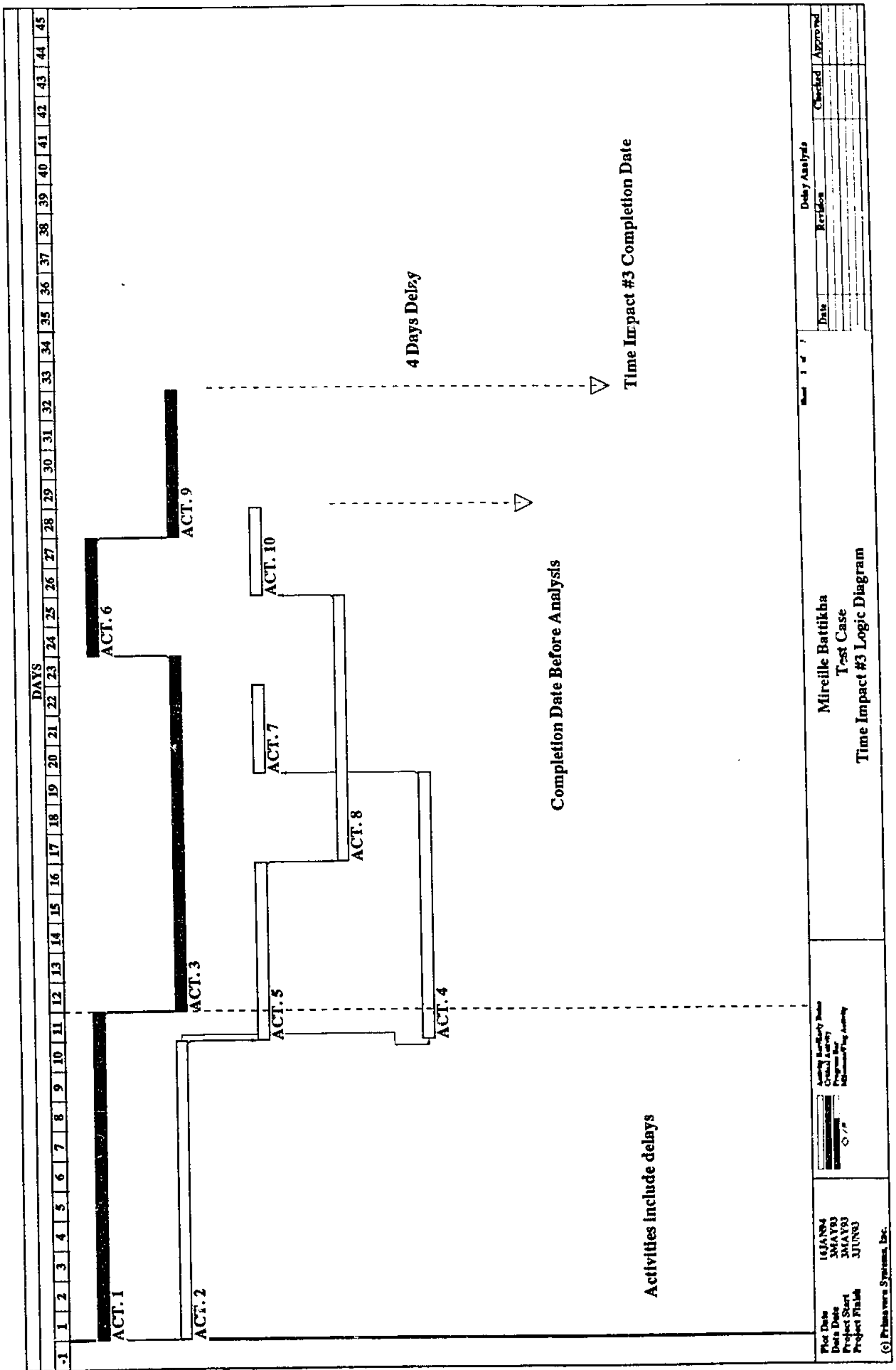

Fig. 3.15. Time Impact #3 Technique

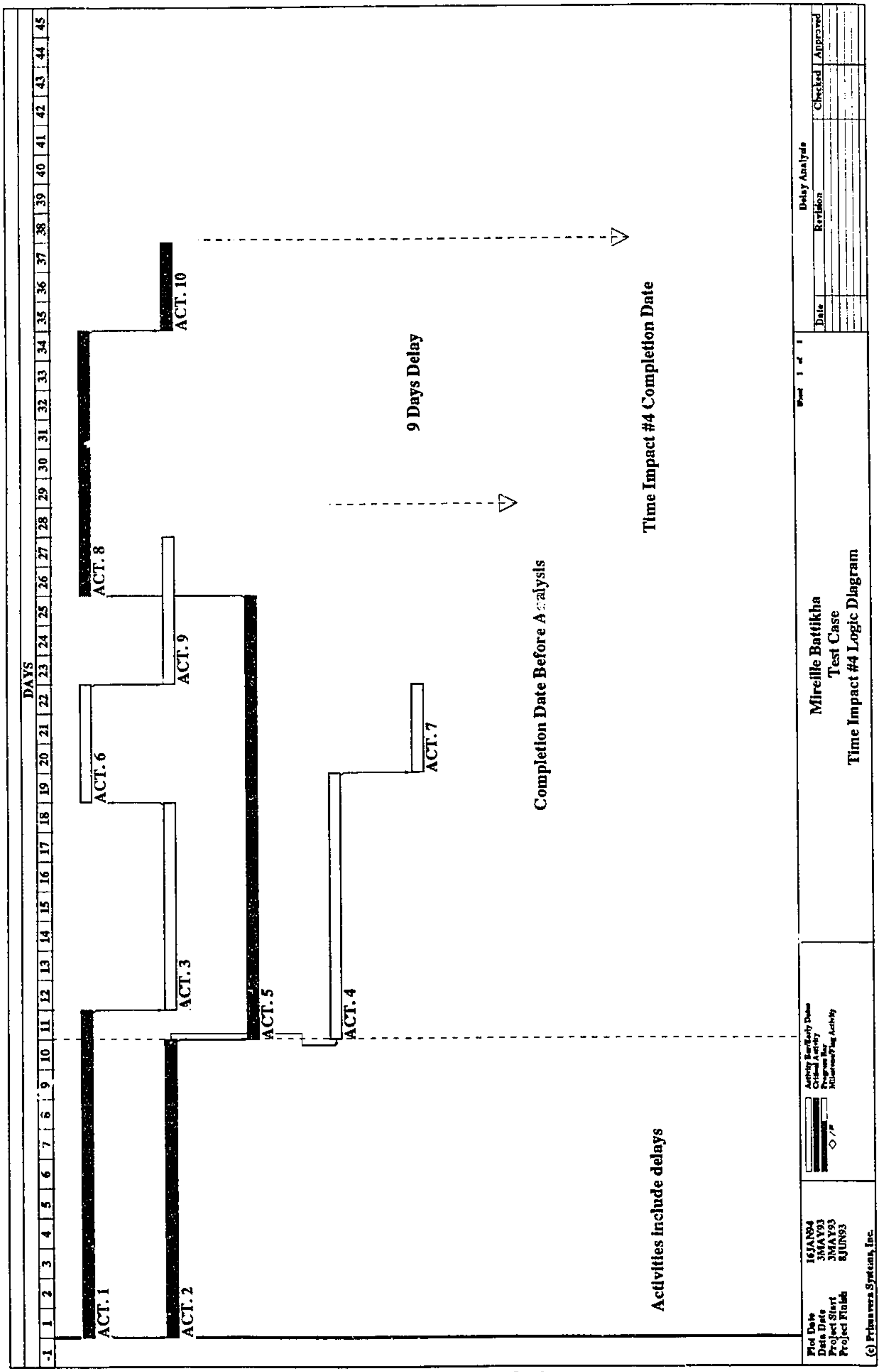

Fig. 3.16. Time Impact #4 Technique

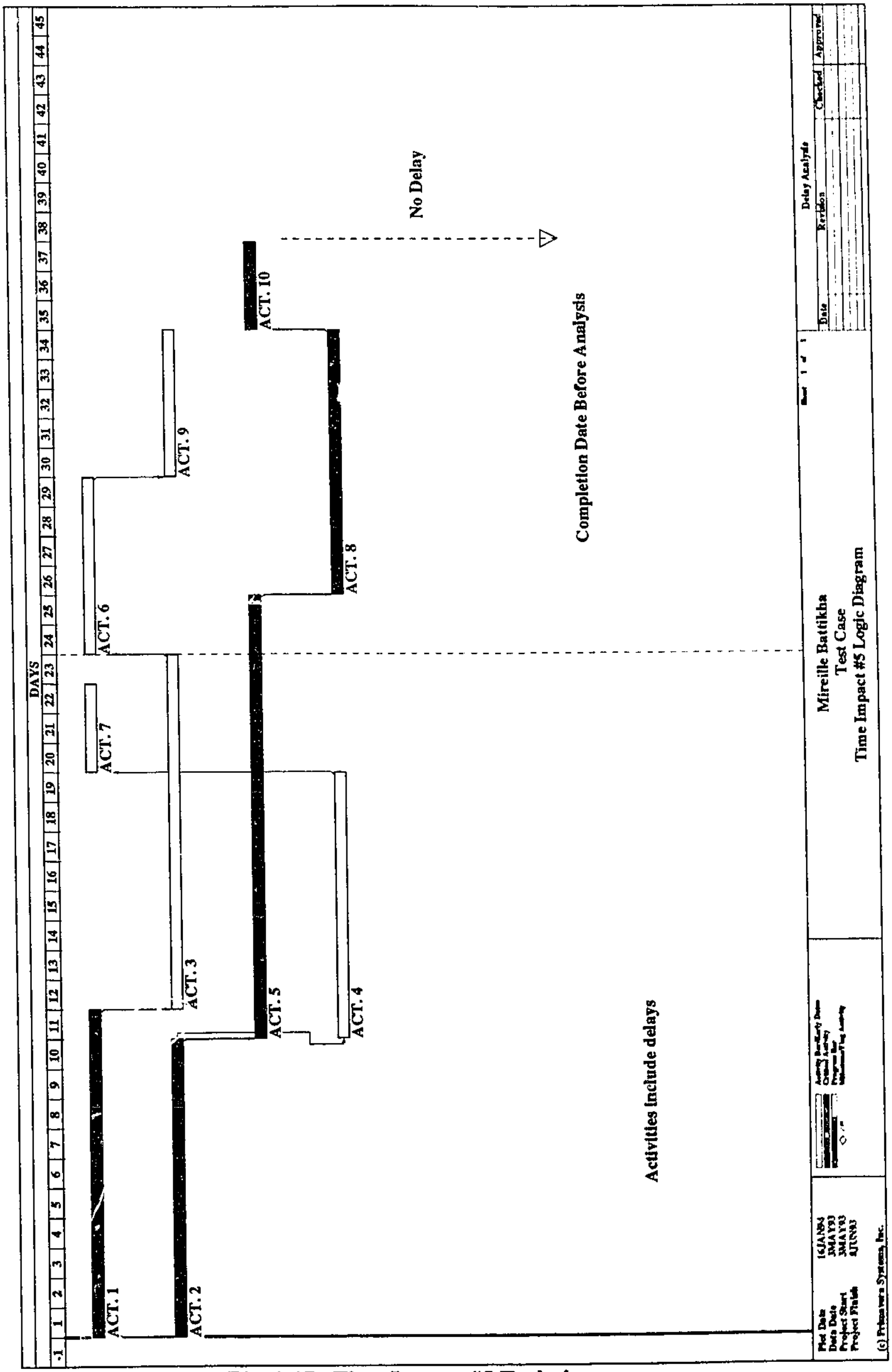

Fig. 3.17. Time Impact #5 Technique

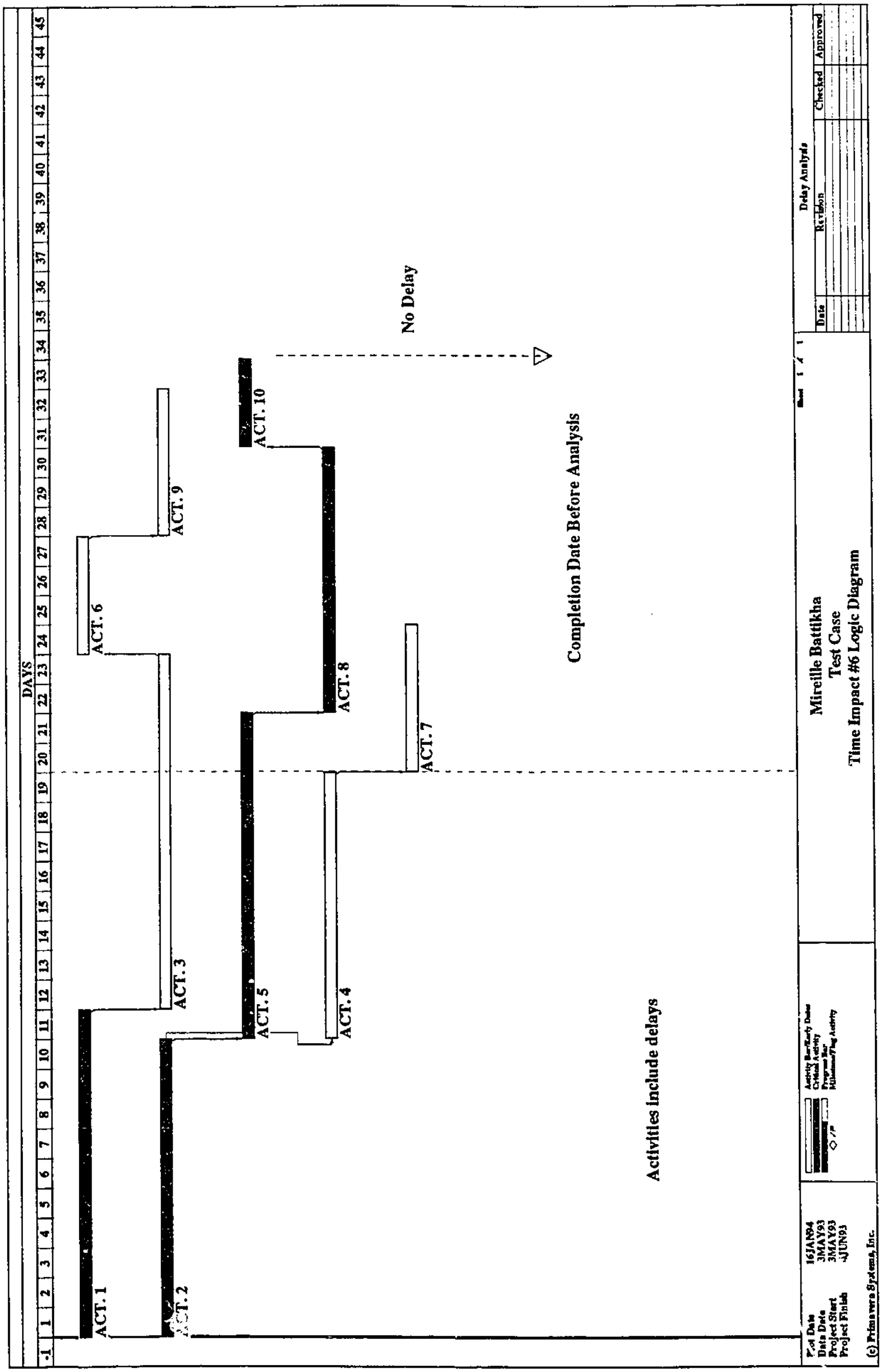

Fig. 3.18. Time Impact #6 Technique

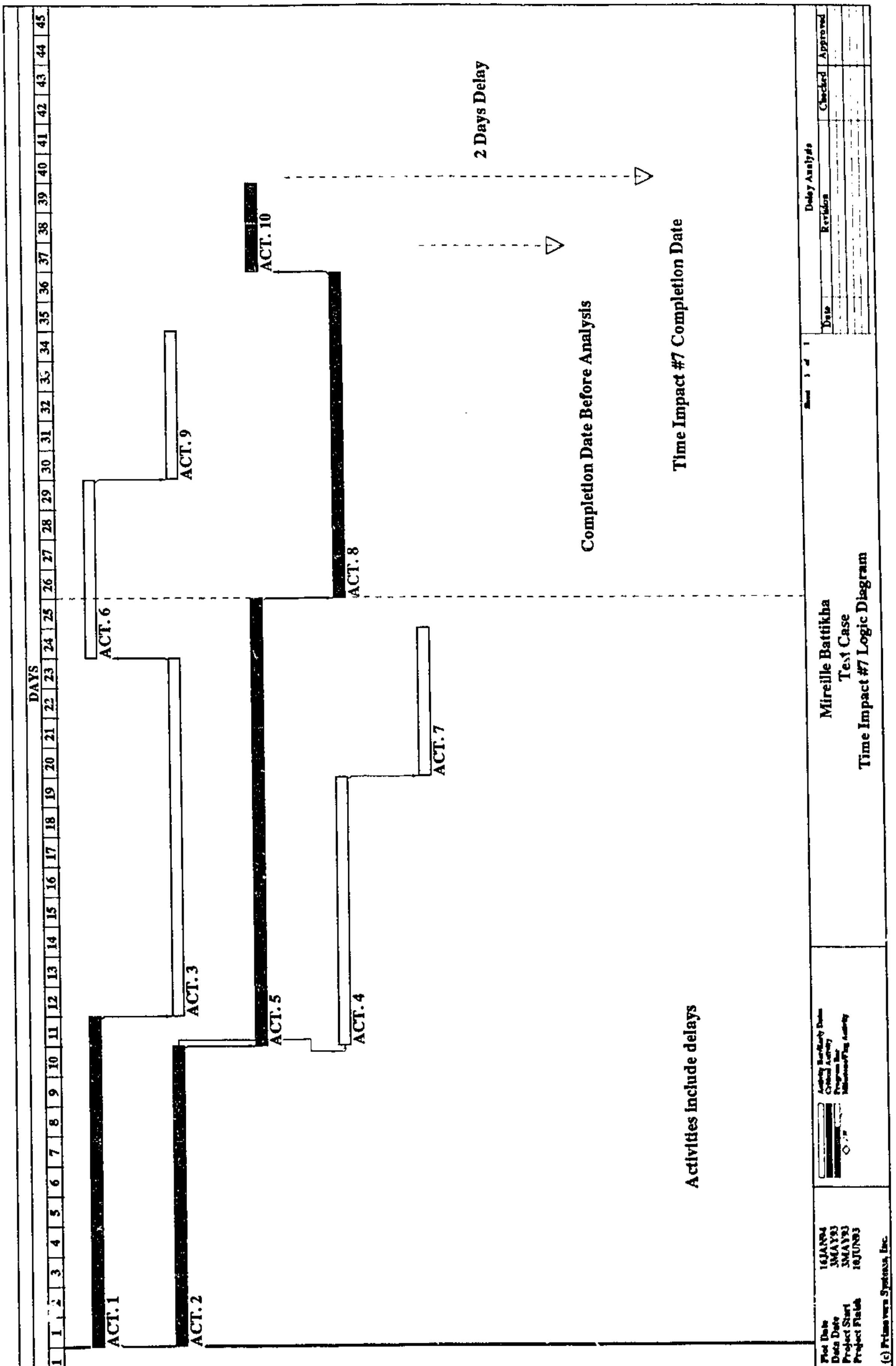

Fig. 3.19. Time Impact #7 Technique

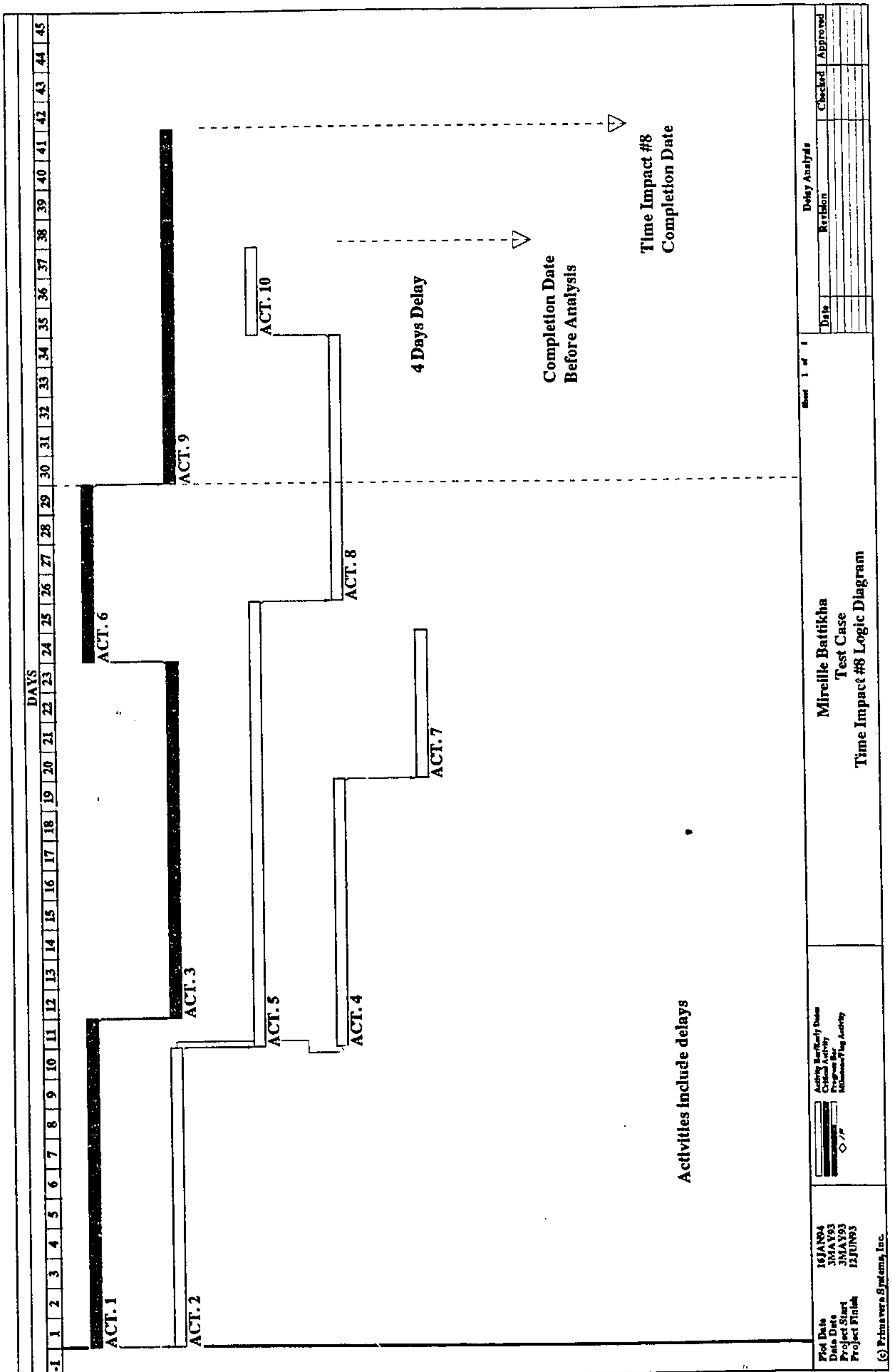

Fig. 3.20. Time Impact #8 Technique

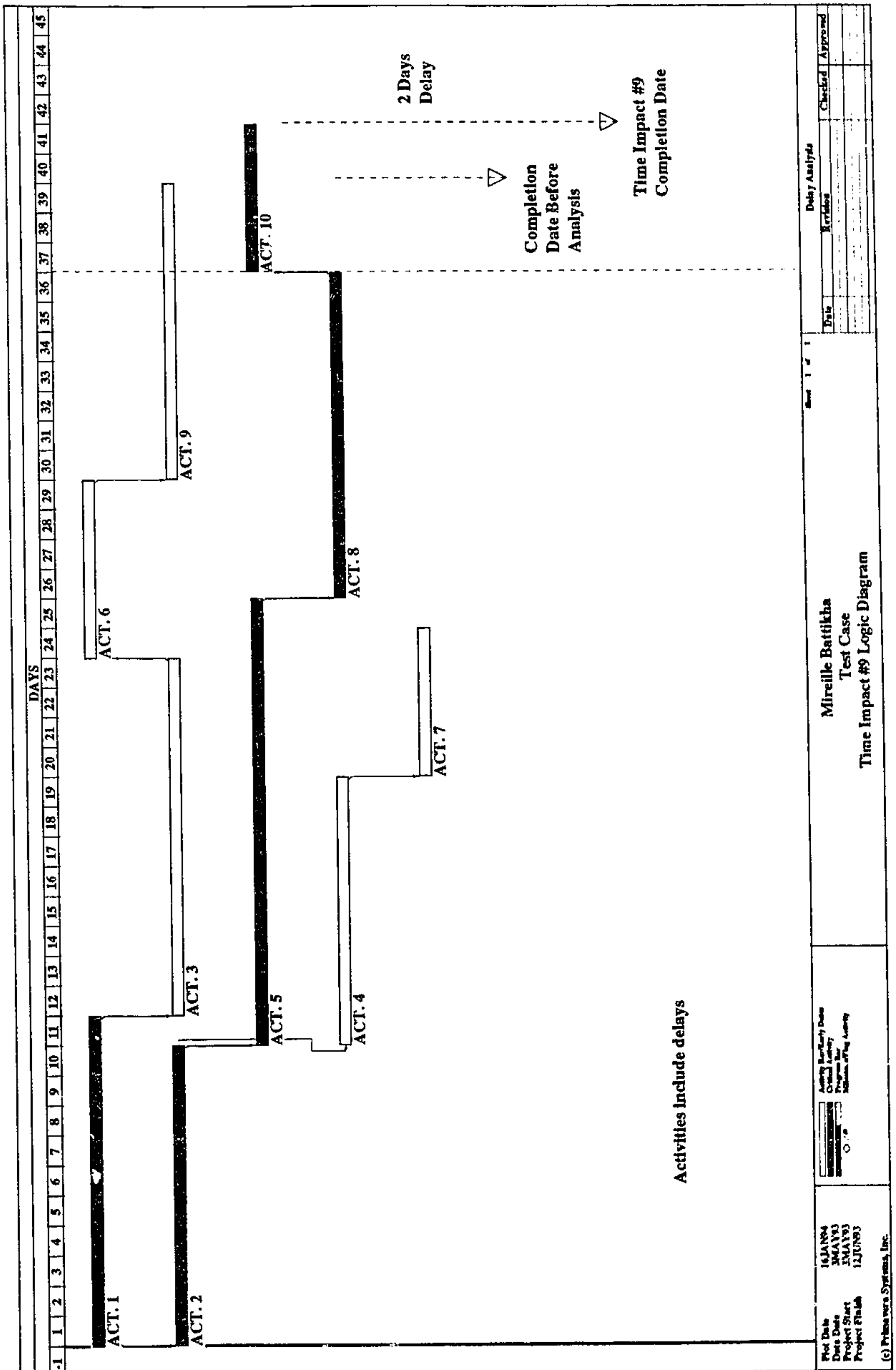

Fig. 3.21. Time Impact #9 Technique

3.3.7 Isolated Delay Type analysis

When applying the isolated delay type technique, each party's delays are analyzed separately. The contractor's delays are incorporated into the schedule to determine the basis for compensation entitled to the owner. The owner's fault delays, or the excusable compensable and noncompensable, when inserted into the schedule will allow to measure the amount of time that the contractor is entitled to. However, the quantification of compensable time is measured by including the excusable compensable delays into the schedule.

i) Isolated Delay Type; Contractor's delays

For the test case under study, two time periods were defined for the isolated delay type technique. Starting with an as-planned schedule, only the nonexcusable delays related to the first time period which extended till the twentieth day, were inserted in the schedule. This adjusted schedule duration of 29 days was compared with the as-planned duration of 23 days, and the 6 days difference represent the delays during the first time period that the contractor is responsible for, as shown in Fig. 3.22. Similarly, for the second time periods which covered the rest of the schedule duration, the nonexcusable delays that occurred during that period were incorporated into the previous adjusted schedule of 29 days duration, and a new calculated schedule duration of 32 days was generated, as shown in Fig. 3.23. The discrepancy between the two schedules, which resulted in 3 days, is the amount of delay that the contractor is responsible for, during the second time period.

Adding the results of both time periods, i.e. 6 and 3 days for the first and the second

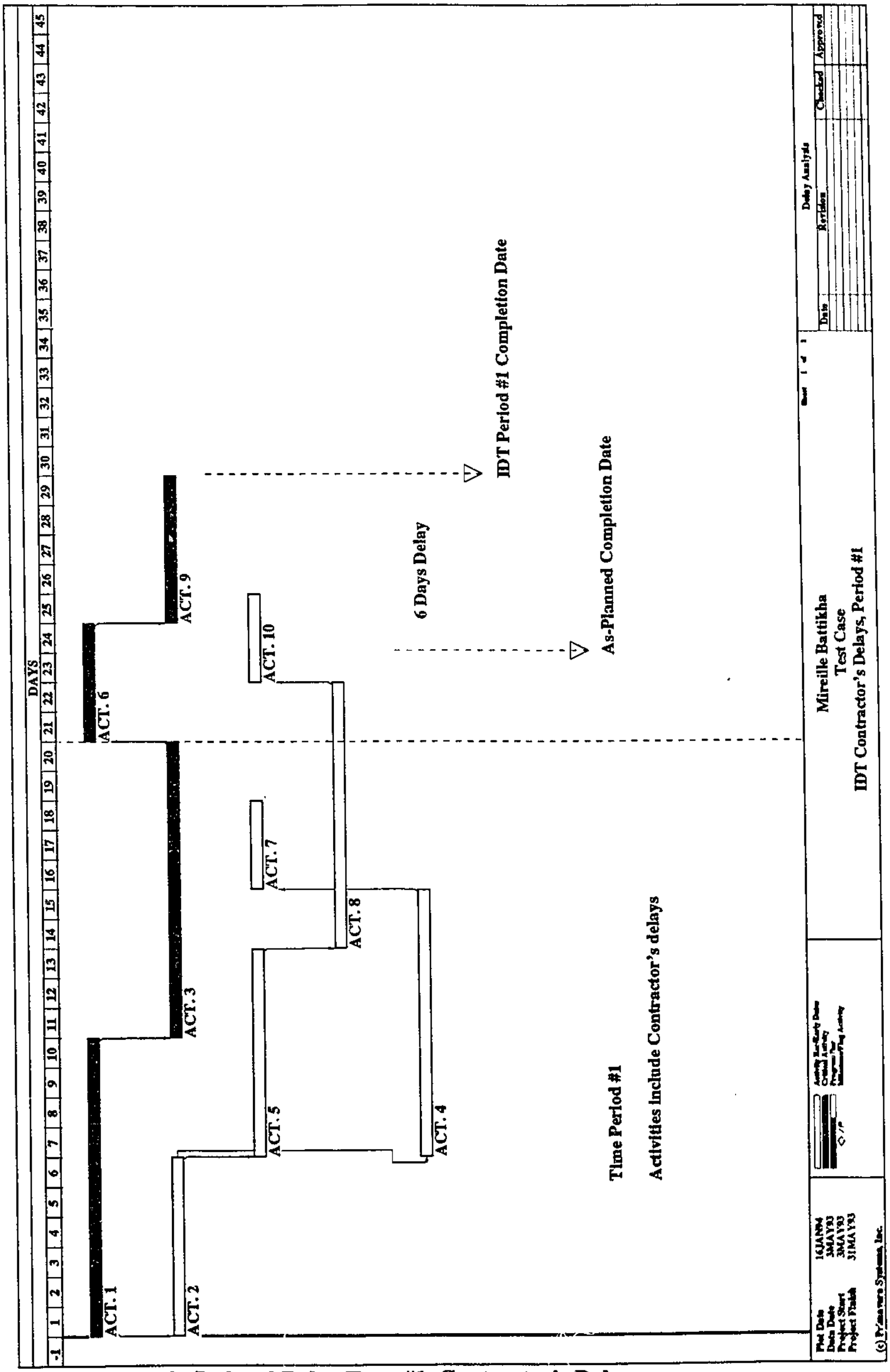

Fig. 3.22. Isolated Delay Type #1, Contractor's Delays

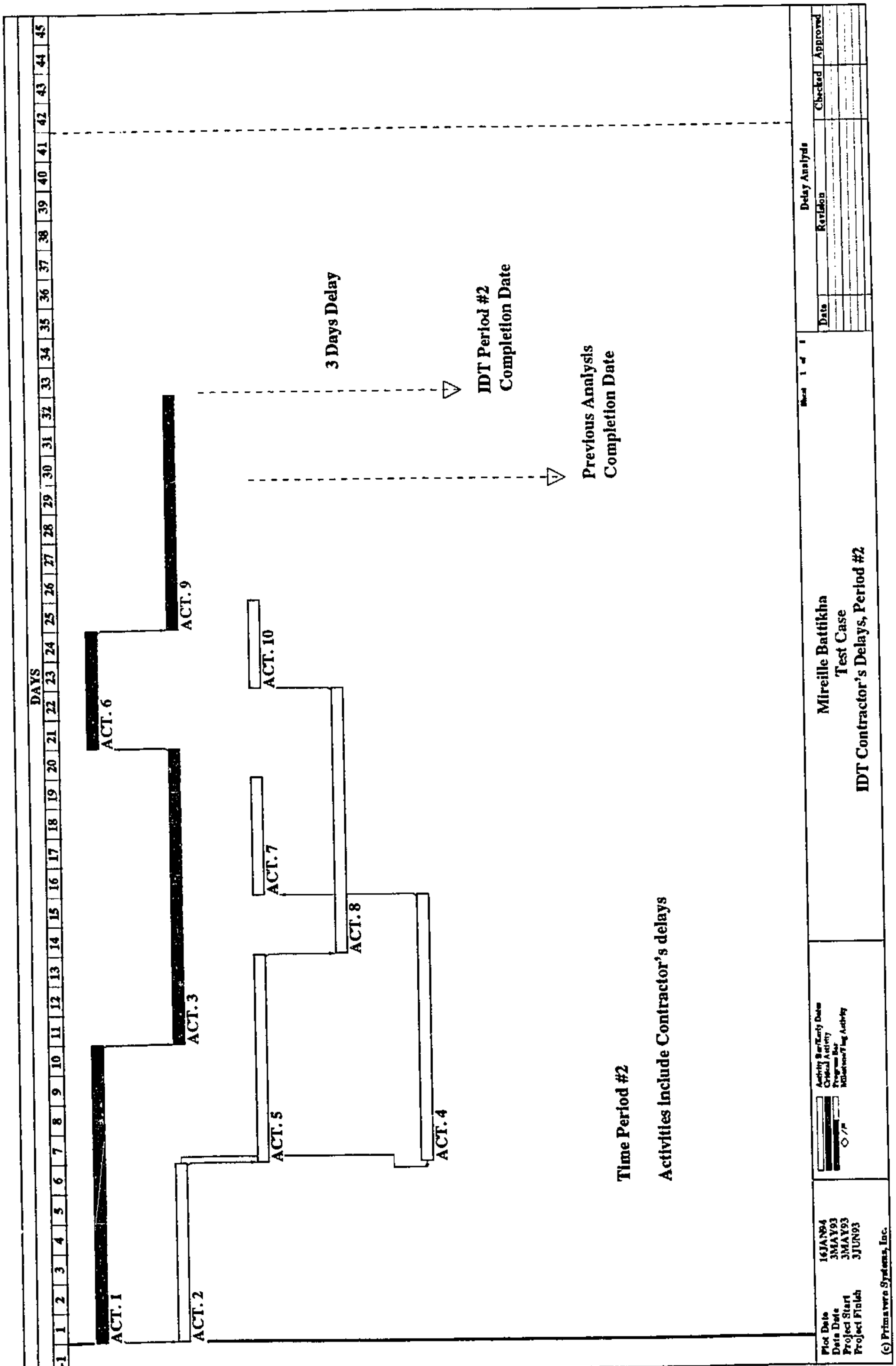

Fig. 3.23. Isolated Delay Type #2, Contractor's Delays

period respectively, gives a total of 9 days delay caused by the contractor.

ii) Isolated Delay Type; Owner's delays

Regarding the delays caused by the owner, the excusable compensable and the excusable noncompensable delays related to the first time period, were incorporated into the as-planned schedule, and an adjusted schedule duration was determined, as shown in Fig. 3.24. The 32 days schedule duration was compared to the 23 days original duration, and the time variance of 9 days is attributed to the delays caused by the owner during the first time period.

The previous schedule of 32 days duration was used for the basis of analysis in the second time period. Only the owner's fault delays, falling into the second period are included into that schedule, and the new schedule duration of 39 days was compared to the 32 days previous schedule duration, as shown in Fig. 3.25. The 7 days of difference between the schedules represents the amount of time that the contractor is entitled to extension of the project duration during the second period.

The delays caused by the owner, i.e. the 9 and the 7 days, for both time periods together, resulted in a total of 16 days delay due to the owner.

The isolated delay type technique attempts to address the issue of scrutinizing delay types during the analysis, and the systematic approach by applying relevant time periods through the schedule. However the problem of concurrency is disregarded, which could

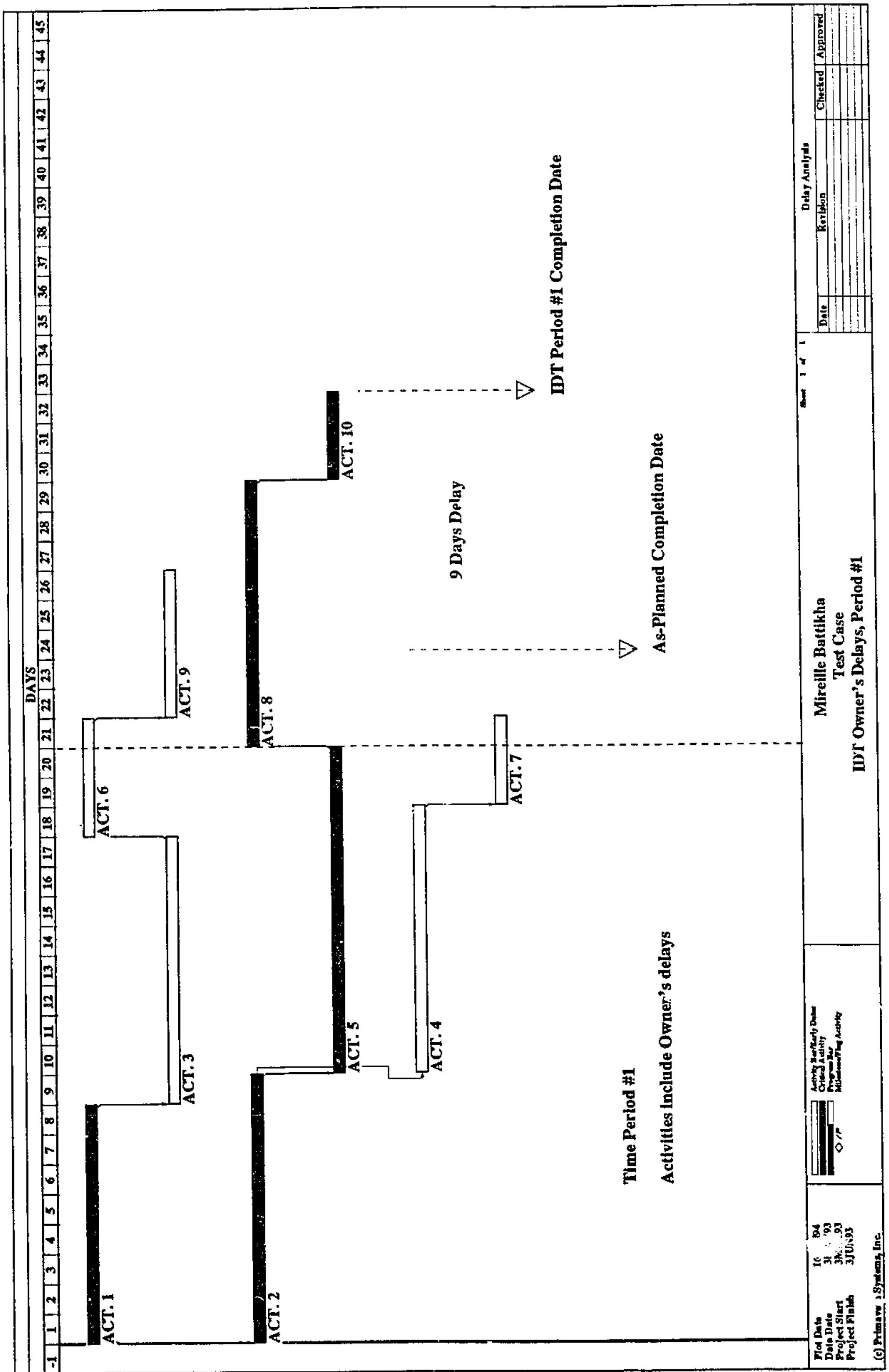

Fig. 3.24. Isolated Delay Type #1, Owner's Delays

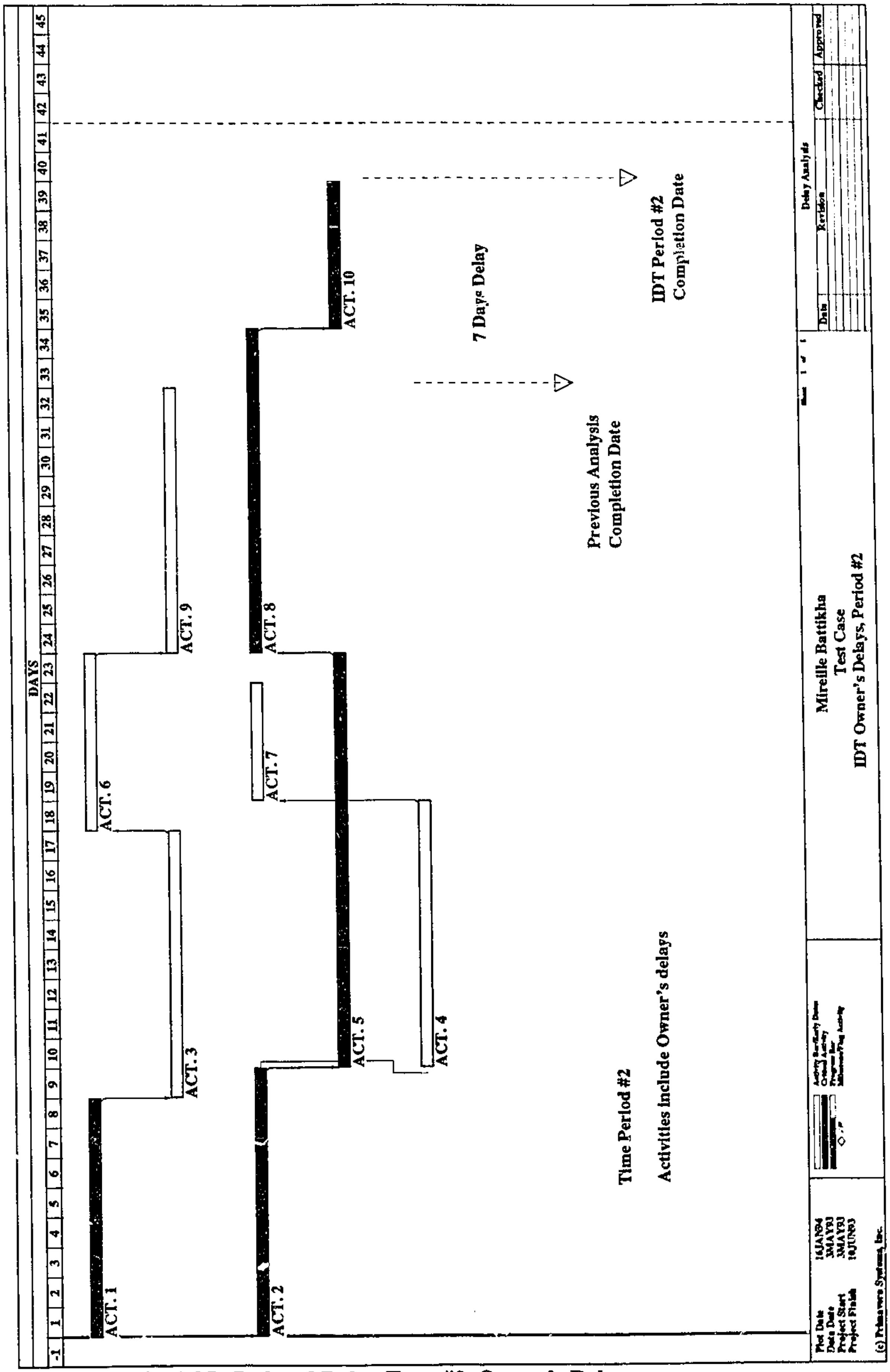

Fig. 3.25. Isolated Delay Type #2, Owner's Delays

result in an overstated amount of delays requested for. For this test case considering the delays due to both parties, the 9 days delay due to the contractor and the 16 days due to the owner, resulted in 25 days total overrun of the project, however the total delay of the project's duration is in fact 18 days only. This inaccuracy represents one of the shortcomings of the isolated delay type technique. In addition the analysis relies on an as-planned schedule to start the systematic analysis, and follow with the schedule comparisons, and each generated schedule becomes the basis for the following analysis. This as-planned schedule is sometimes unavailable in the analysis, and even if available, its critical path would be hypothetical one, and does not represent the real facts as they happened in real life. Further all the generated schedules, must be done sequentially after each other respecting their preceding schedules, which is cumbersome when an analysis is required for only certain specified delays during the project.

3.3.8 Concurrent delays analysis

The analysis of concurrent delays (Kraiem et al. 1987) provides an efficient way to handle concurrent delays after the fact. This technique consists of performing different adjusted schedules, by excluding from the as-built schedule, where all types of delays have been identified, the relevant type of delay to be calculated. This difference between the as-built and the adjusted schedule is the amount of the delay calculated. For the test case the following durations for the different types of delays were calculated (Kraiem et al. 1987):

Total delay = 18 days

Nonexcusable delay = 1 day

Compensable delay = 2 days

Concurrent compensable and nonexcusable delays = 3 days

Concurrent with excusable delays = 2 days

Excusable delay for entire project = 10 days

The excusable delays were obtained by adding all other delays, then subtracting this summation from the total delay of 18 days, that gives 18 - 8 = 10 days. The analysis is done after the fact and identifies all the concurrent delays, however the calculation of the excusable delays is inaccurate since it is left at the end of the analysis and a subtraction is performed. However, when the same analysis technique is applied to the excusable delays in question by removing them from the as-built schedule as shown in Fig. 3.26, the schedule duration would result in 39 days, and the difference of 2 days between the as-built duration of 41 days, when compared to the 39 days, is the amount of excusable delays that must have been found instead of the 10 days. This amount, if added to the 8 days of all other delays would result in 10 days total delay, whereas the real total delay is 18 days. Thus this technique is not accurate in determining the amount of delays, and could be performed to the favour of a certain party by leaving the other delays to the end and subtracting the ones which favours that party. However, it provides a good adjustment in identifying the type of concurrent delays, by allocating on the as-built schedule a different code to each one.

3.4 Results of the Assessment

By examining each delay analysis technique, it was generally found that none of the existing techniques would be effective in providing accurate results if applied alone. Therefore, there is a need to propose a new delay analysis technique that would allow in

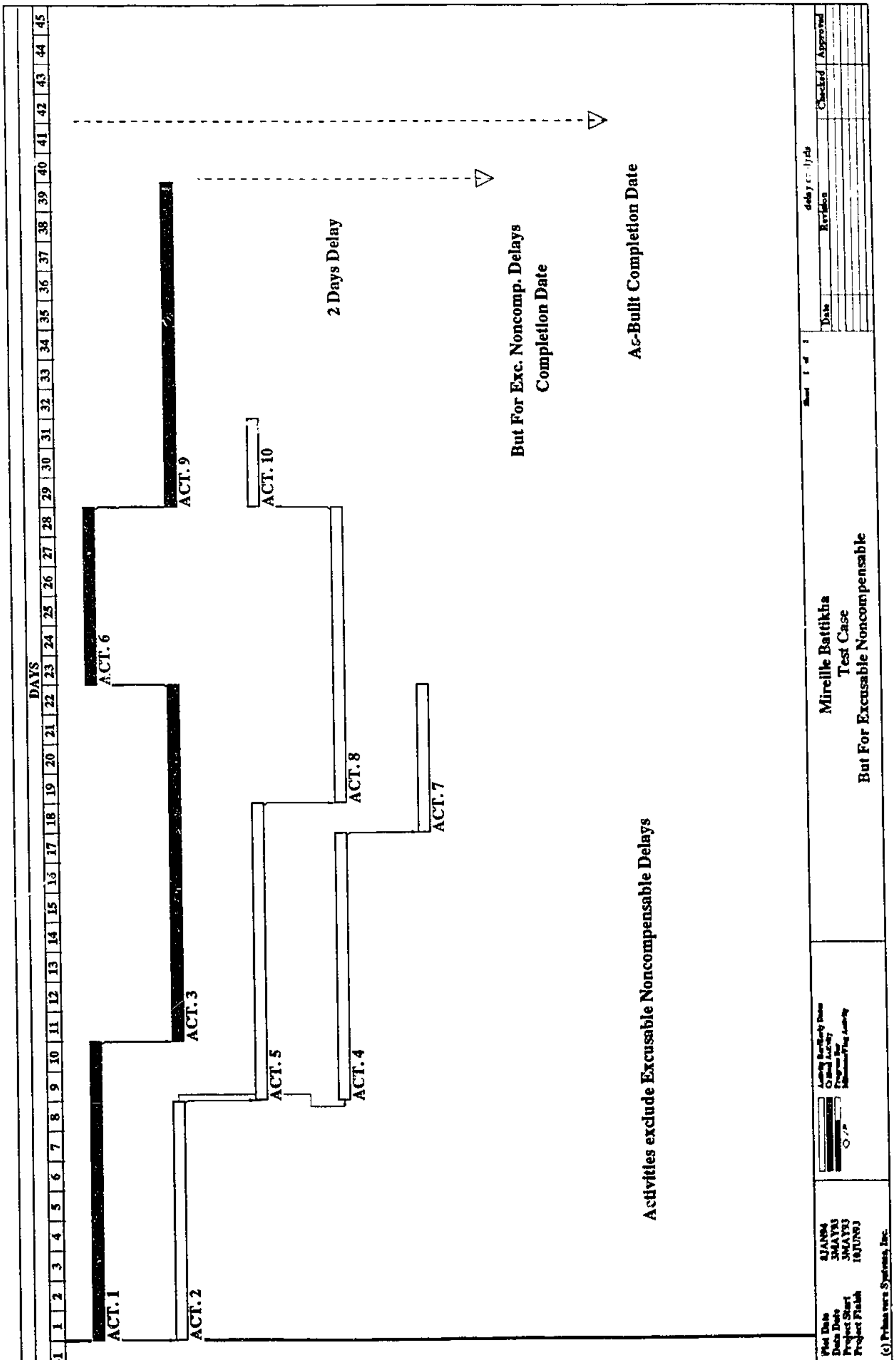

Fig. 3.26. Concurrent Delays Analysis, Excluding EN Delays

addition to its new approach, the combination of some advantages of more than one technique, in order to provide a credible and objective method of analysis. The following summarises the results extracted from applying the current delay analysis techniques to the test case under consideration:

Global impact; 38 days

Net impact; 18 days

Adjusted As-Built CPM; 18 days

But For contractor's delays; 2 days, differing from 1 day (Fig. 3.9)

But For owner's delays; 9 days, differing from 12 days (Fig. 3.10)

Snapshot; 18 days (to be apportioned between owner and contractor)

Time Impact; 30 days (to be apportioned)

Isolated Delay Type, contractor's delays; 9 days

Isolated Delay Type, owner's delays; 16 days

Concurrent delay analysis, total delay; 18 days:

. nonexcusable delay; 1 day

. compensable delay; 2 days

. concurrent compensable and nonexcusable delays; 3 days

. concurrent with excusable delays; 2 days

. excusable delay for entire project; 10 days, differing from 2 days (Fig. 3.26)

In order to ensure the accuracy of a delay analysis, three main issues must be considered, these are: the right classification of delay types, the resolution of concurrency, and the analysis of delays in their real time and critical path. Without assessing the types of delays a wrong judgement for entitlement might occur. Concurrency or overlap of delays must be resolved in order to avoid an overstatement of time extension requested for. It is important to ensure that the delays are analyzed using the actual critical path of the schedule since this path changes during the schedule analysis. Some delays might appear on a critical path in the adjusted schedule, while in the actual schedule they are not critical.

To summarize the advantages and disadvantages of these techniques, they were grouped into two levels of sophistication. The first being simplistic, which includes the global impact, net impact, and adjusted as-built CPM techniques. The second is detailed, which includes the but for, snapshot, time impact, isolated delay type, and concurrent delays analysis techniques. The detailed techniques are more reliable and preferred for preparing delay analyses, since they have more advantages than the simplistic techniques.

The major problem with the simplistic approach techniques is that they do not scrutinize delay types, as a result delays caused by one party might be considered the responsibility of the other party. These techniques are applied after the fact, which might be too late if damages need to be calculated during the project. In addition the reliance on an as-planned schedule generates another disadvantage, since it does not represent the real critical path, and could be unavailable at the time of the analysis. The global impact has an additional deficiency, which is the overstatement of total amount of delays, due to the problem of concurrency which is disregarded.

The detailed approach techniques, classify delay types, however the snapshot and the time impact do not, and they require a further analysis to apportion entitlement between owner and contractor. The time impact has another disadvantage since it deals with each delay separately, it does not address the problem of concurrency, and the analysis may become too complicated if too many delays are encountered. The but for, the isolated delay type and the concurrent delays techniques scrutinize delay types, but they are applied to the favour of one party and the results are inaccurate, since the total amount of delays is overstated, as in the isolated delay type or understated as in the but for, and unfavourably calculated like the excusable delays in the concurrent delays analysis. However the systematic approach of the time impact, the snapshot, the isolated delay type, provide a dynamic analysis at the time of the delay, thus they are not performed after the fact. The advantages that the concurrent delays analysis has over the others is in the adjustment of concurrent delays, and the reliance on the as-built schedule. The concurrent delays, and the isolated delay type techniques attempt to calculate the amount of compensable delays, though inaccurately.

Analyzing the existing delay analysis techniques, reveals a need for improving the analysis process. Thus, an objective technique, that considers concurrent delays, classifies delay types during the analysis, determines amount of compensable delays, can be performed during or after the fact, relying on an as-built or on an as-planned schedules, being accurate, and capable of integrating with cost quantification analyses, will be beneficial and cost effective to all parties involved in construction disputes arising from delays. In order to achieve these objectives, a new delay analysis technique called MIA technique, was proposed (Battikha et al. 1994a).

3.5 The Proposed Delay Analysis Technique

The as-built schedule is a more real and factual schedule where all dates and delays, and logic or sequence of activities are shown as they happened. A technique that is capable of analyzing causes and effects of delays, requires an actual schedule that shows the real durations of delays, and their types, with the actual critical path. This data could be gathered from the field after the fact or during the project and stored in a computerized database. These records are very important in calculating the durations and building an as-built schedule. The use of the computer is of great value, since it allows a faster retrieval of information and specially when their number is overwhelming. The use of the computer environment will be discussed in a later chapter, and the description of the new delay analysis is as follows:

The delays are to be classified as excusable compensable (EC), excusable noncompensable (EN), or nonexcusable (NE). This is done using the results of a consultation of an expert system and/or an expert. After that, a further analysis is performed to adjust concurrent delays as to which becomes excusable, when on parallel critical paths a delay occurs at the same time with an excusable delay, then it becomes excusable noncompensable. This adjustment is to be performed within the database software, thus an adjusted as-built schedule is performed.

Thereafter, the delays due to each party are separated. The owner responsibility delays are the excusable compensable and the excusable noncompensable. Where as the nonexcusable delays are the contractor's responsibility. This separation is performed after the concurrent delays have been analyzed and adjusted. Now, all adjusted types of delays are classified in terms of the opposite parties, owner and contractor. Further, the systematic approach in performing stop actions to the schedule at any time and even with ongoing delays is applied. Those windows or snapshots will allow a closer look at the cause and effect of delays and will show the delays in their actual context of time and their relation with the real critical path. Then a further analysis is required to obtain the amount of delays due to each party, to be used as a basis for quantifying damages, and the excusable compensable delays are determined.

The proposed technique attempts to address all the issues that will ensure an accurate delay analysis. Time periods are determined based after a delay or series of delays have occurred. The technique respects the different delay types within the delaying events and applies only the relevant portion of the delays in the time period. Comparing the project completion date of the schedule before and after removing the delaying events may generate a change in the project completion date. This discrepancy is attributed to the delay(s) that were excluded from the adjusted schedule. The following is a step by step procedure that was followed in applying the proposed delay analysis to the test case:

1. A realistic as-planned schedule (Fig. 3.1) was obtained. This was taken as a base to establish an adjusted as-built schedule (Fig. 3.2), after incorporating all the delays into the original schedule.
2. The Expert System (Delay Advisor) was consulted to classify delay types, in the form

of Excusable Compensable (EC), Excusable Noncompensable (EN) and Nonexcusable (NE), these delays were adjusted for entitlement and concurrency and then stored in the database.

3. Snapshot periods were chosen to be performed from the as-built schedule, in this test case the first snapshot was selected for the first 20 days and the second one for the remaining period that ended at day 41. For the first snapshot period all the delays due to both parties were inserted in the as-planned schedule of 23 days duration, and the project duration was recalculated to become 34 days. This was compared to the as-planned schedule, which resulted in 11 days total overrun due to both parties. This adjusted schedule was called As-Built Snapshot 1, or ABS1 = 34 as shown in Fig. 3.27. Using the same procedure the second snapshot period, As-Built Snapshot 2 schedule, or ABS2 (Fig. 3.28) was found to be equal to 41 days. Comparing these two snapshots resulted in a difference of 7 days delay. Therefore, the total overrun time was 11 + 7 = 18 days which corresponds to the total time extension due to both parties.

4. ABS1 and ABS2 were used to determine delays that each party was entitled to. EC and EN which are the owner's responsibility were excluded from the ABS1 schedule and the new project schedule was calculated to result in 26 days. This was referred to as BOS1 or But For Owner Snapshot 1. BOS1 was compared with ABS1 schedule that had a duration of 34 days, 8 days delay due to the owner, were encountered during this time period, as shown in Fig. 3.29. The same procedure was followed for the second snapshot, where delays caused by the owner were excluded from the ABS2 schedule and the new duration for BOS2 schedule was found to be 35 days as shown in Fig. 3.30. This was compared with ABS2 that had a duration of 41 days, and the difference resulted in 6 days

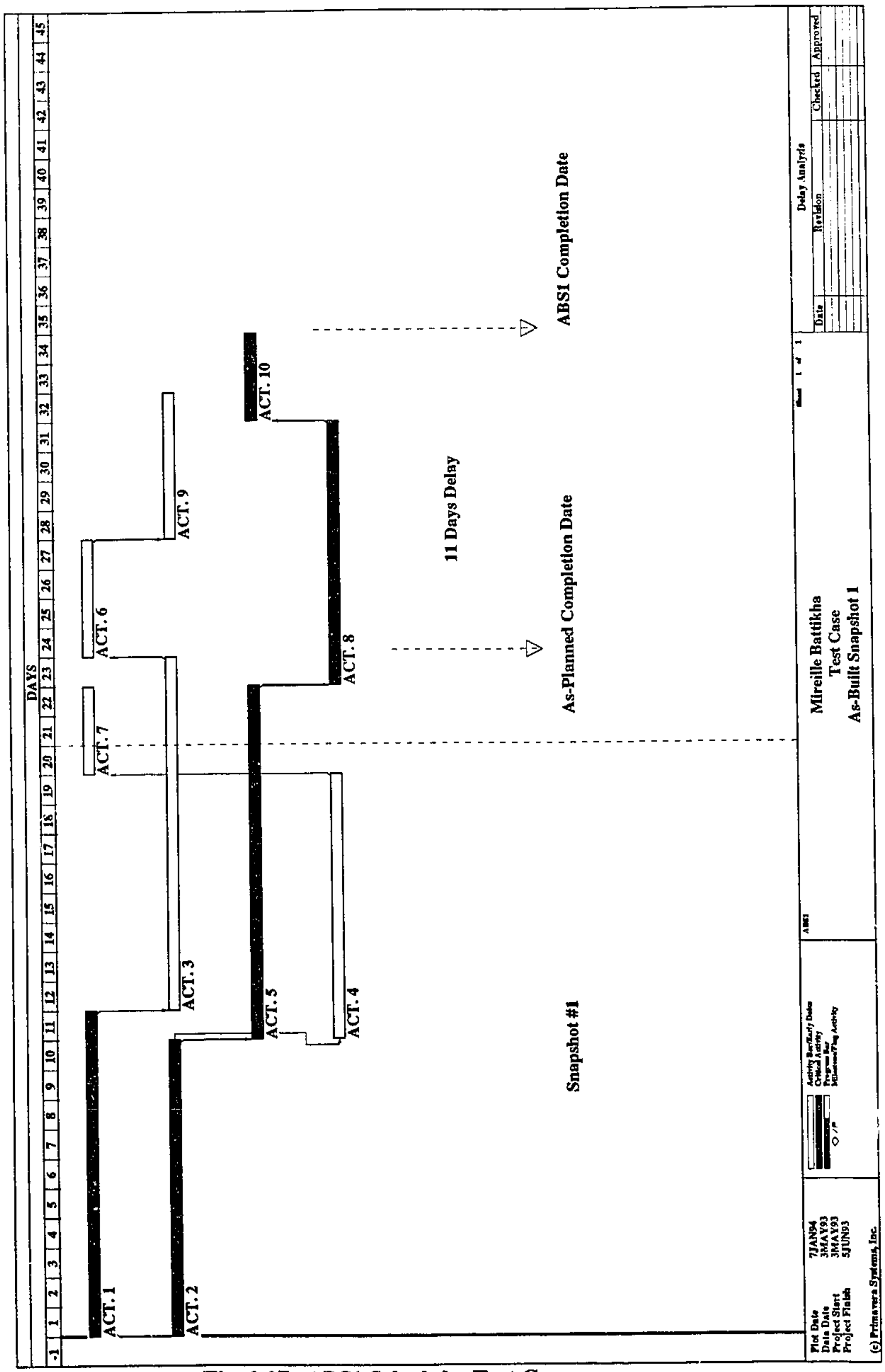

Fig. 3.27. ABS1 Schedule; Test Case

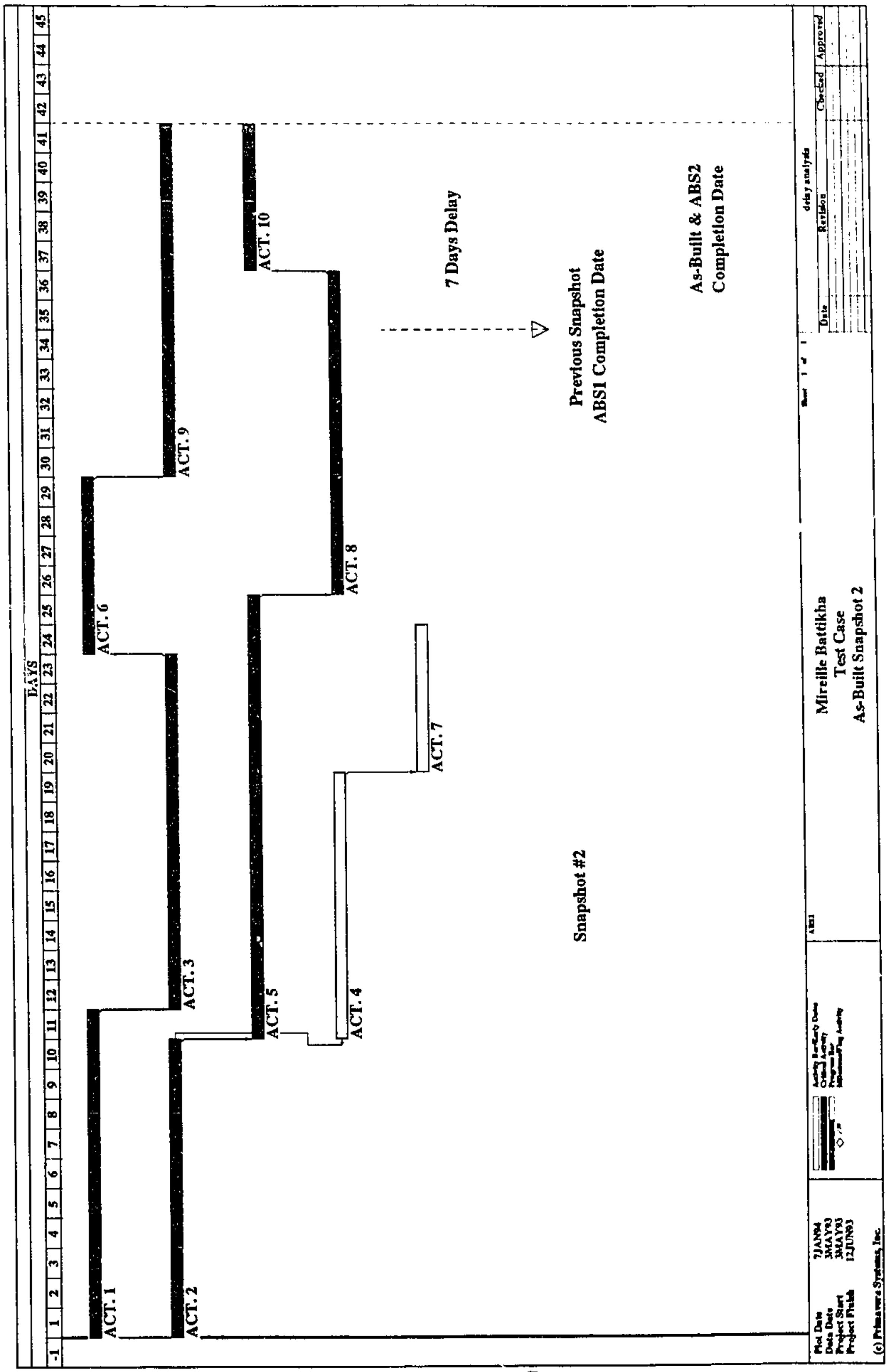

Fig. 3.28. ABS2 Schedule; Test Case

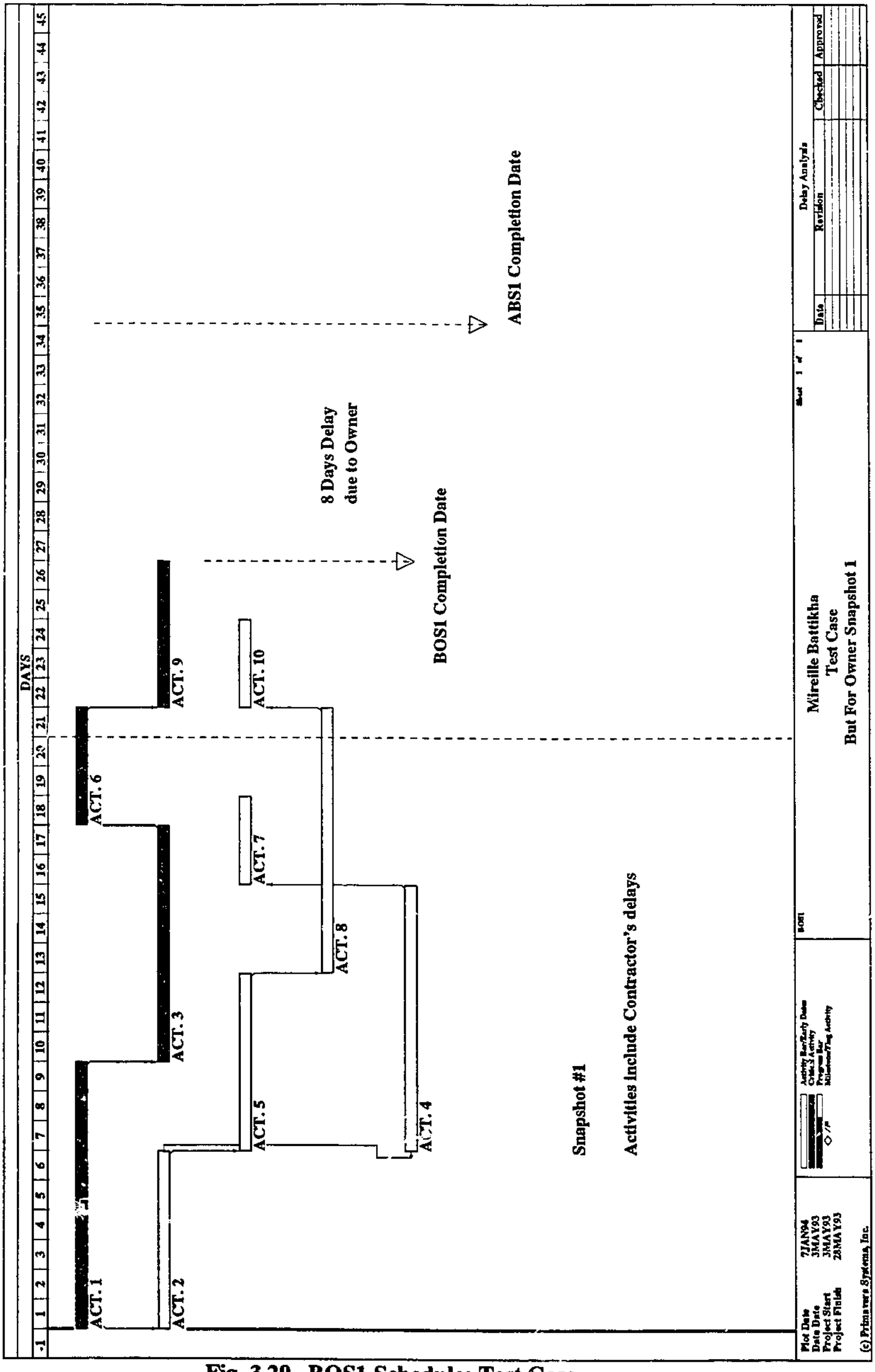

Fig. 3.29. BOS1 Schedule; Test Case

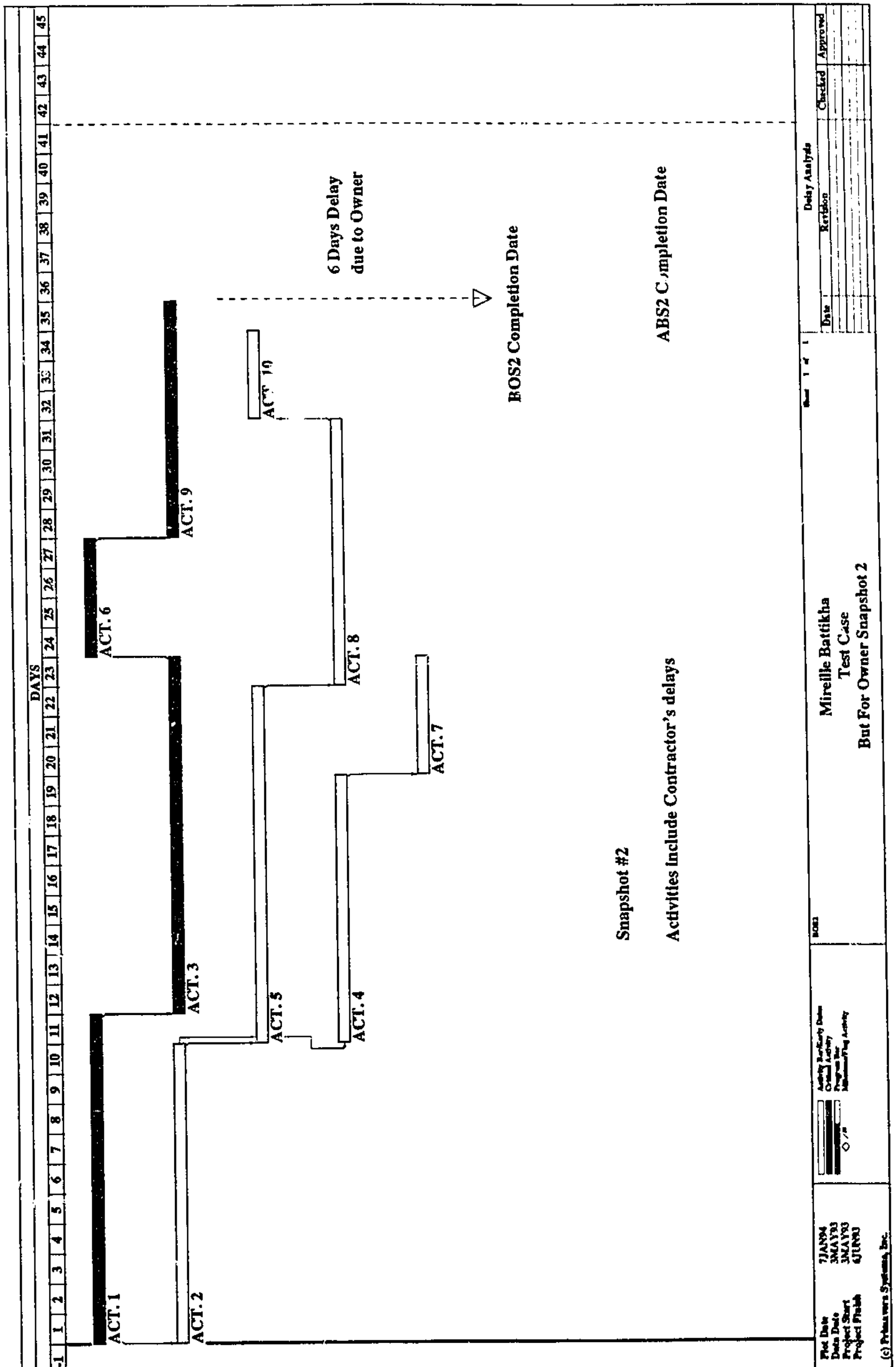

Fig. 3.30. BOS2 Schedule; Test Case

delay due to the owner encountered during snapshot 2.

5. Step 4 was repeated for the contractor, where the NE delays were excluded from the ABS1 schedule, and BCS1 or But For Contractor Snapshot 1, was established which gave 33 days project duration (Fig. 3.31). This was compared with the ABS1's duration of 34 days, and the difference resulted in 1 day delay due to the contractor. Likewise, for the second snapshot the NE delays were removed from the ABS2 schedule and a new schedule (BCS2) with a duration of 41 days was obtained (Fig. 3.32). This did not vary from the ABS2's duration, thus the contractor did not cause any delay during this period. For the purpose of this study, only two snapshot periods were assigned, however, the more snapshot periods are selected, the more accurate the results of the analysis would be.

6. The previous results were analyzed as follows:

ABS1 - (AS-PLANNED) = 34 - 23 = 11 days, total overrun for snapshot 1

ABS1 - BOS1 = 34 - 26 = 8 days, due to the owner

ABS1 - BCS1 = 34 - 33 = 1 day, due to the contractor

The total delay due to both parties was 8 + 1 = 9 days, which is less than the total overrun of the project's duration for the first time period, by 2 days. In order to resolve this discrepancy a weighted ratio was applied by assigning more weight to the party whose delays have had more effect on the schedule. This ratio was applied for each snapshot separately, for example, for the first snapshot where a difference of 2 days existed the ratio was calculated as follows:

11 - 9 = 2 days delay, due to neither party

[(1/9) * 2] + 1 = 1.22 days due to the contractor

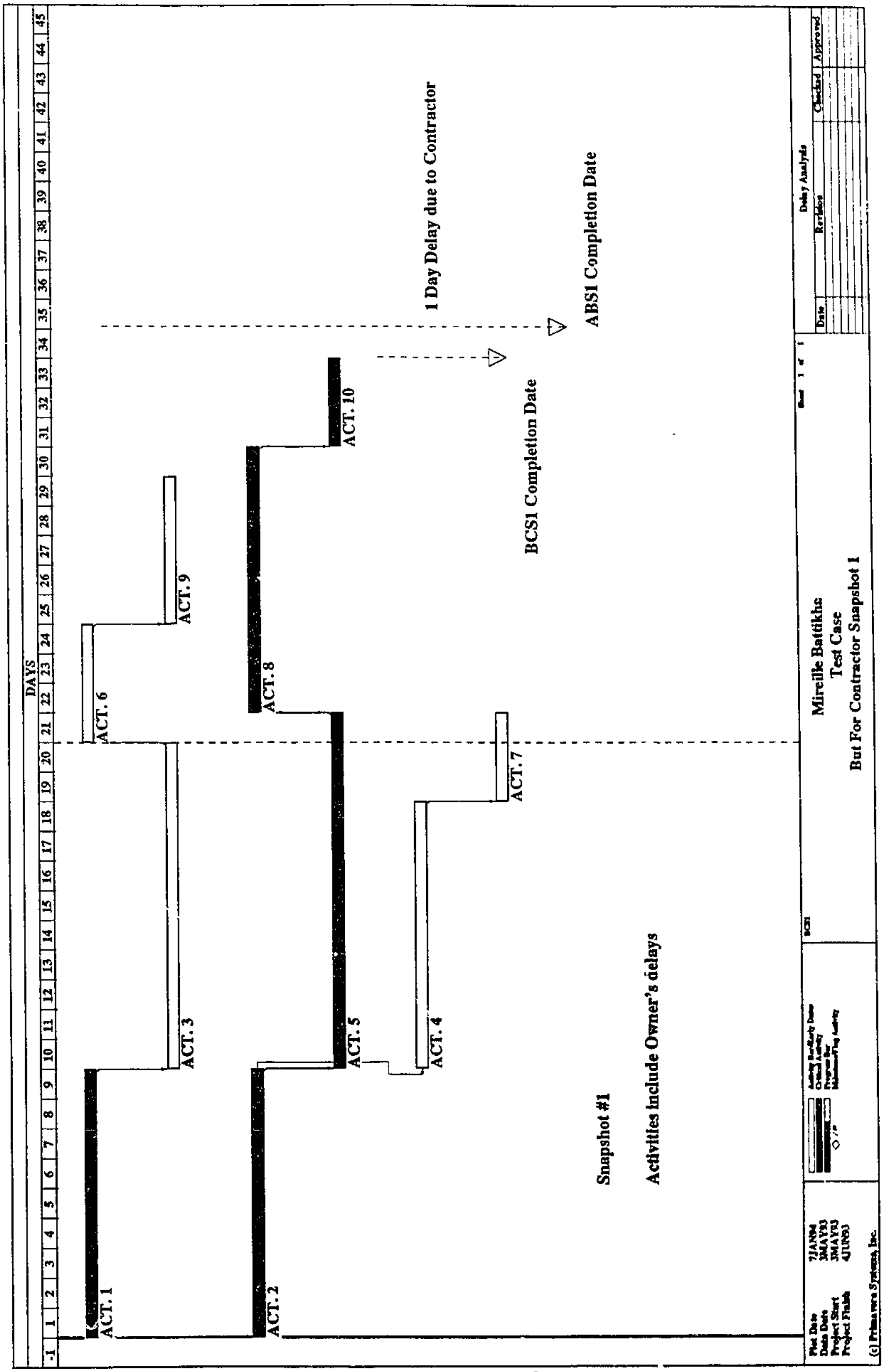

Fig. 3.31. BCS1 Schedule; Test Case

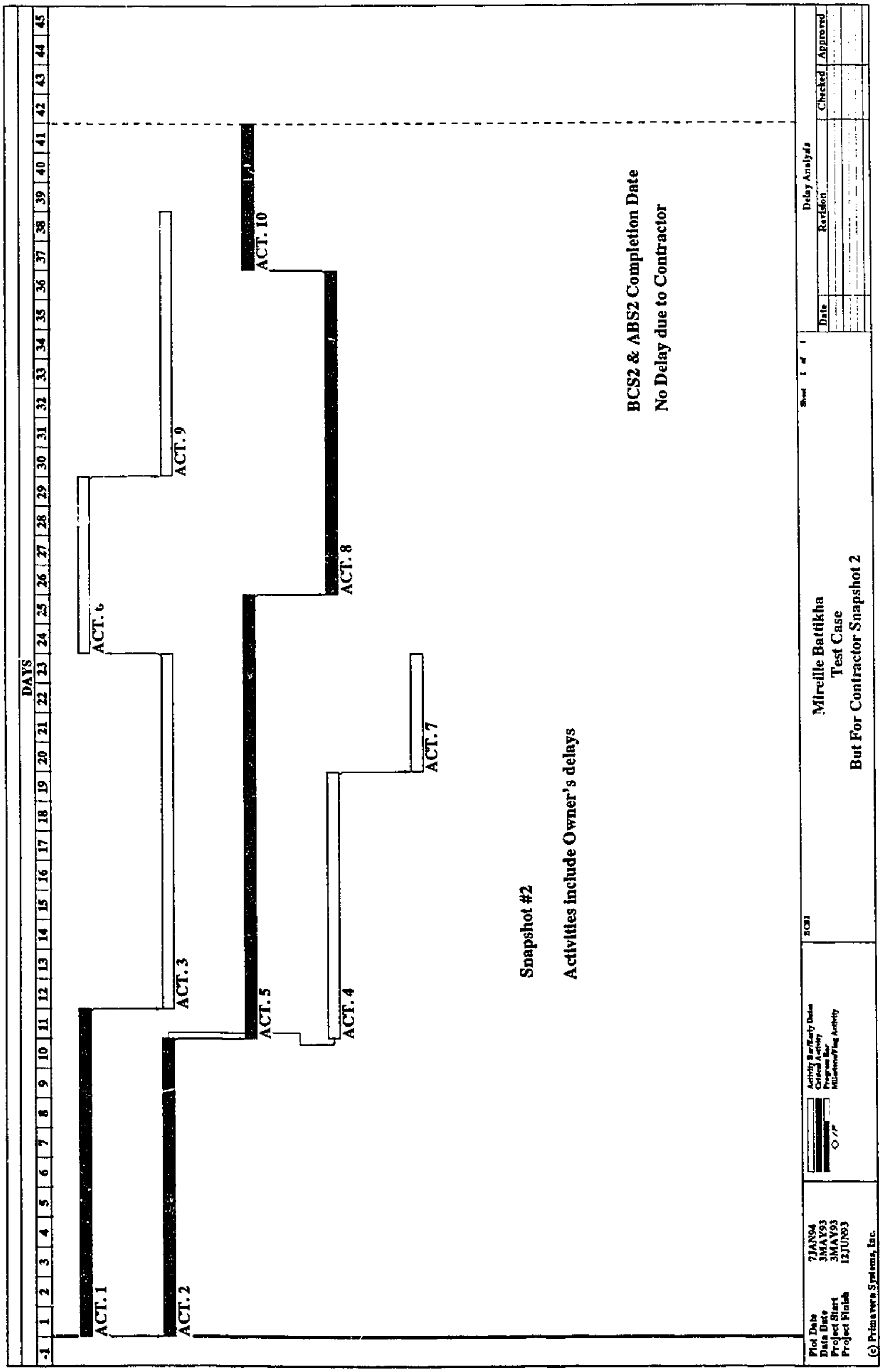

Fig. 3.32. BCS2 Schedule; Test Case

[(8/9) * 2] + 8 = 9.78 days due to the owner

Thus the total delay due to both parties will be equivalent to 11 days for the total overrun during the first snapshot period.

For the second snapshot the same procedure was followed:

ABS2 - ABS1 = 7 days, total overrun during snapshot 2

ABS2 - BOS2 = 41 - 35 = 6 days, due to the owner

ABS2 - BCS2 = 41 - 41 = 0 day, no delay due to the contractor

The delays due to both parties are 6 + 0 = 6, which are less than the total overrun during the second snapshot of 7 days, by 1 day. Therefore the ratio is applied for this period:

7 - 6 = 1 day delay, due to neither party

[(0/6) * 1] + 0 = 0 day, no delay due to the contractor

[(6/6) * 1] + 6 = 7 days, due to the owner

The summation of the adjusted results gives: 0 + 7 = 7 days delay, which is equivalent to the total time extension during the second snapshot period. This leads to a total delay of 11 + 7 = 18 days for both parties. The owner was responsible for 9.78 days in the first snapshot and 7 days in the second which results in 16.78 days of total delays due to owner, or 17 days (rounded). As for the contractor the delays were 1.22 days for the first snapshot, and no delay for the second period, resulting in only one day delay (rounded).

7. Out of these delays, the compensable ones were isolated in order to estimate the extra costs that the contractor is entitled to claim. In order to do so, the excusable noncompensable (EN) delays were excluded from the BCS1, and the schedule duration (BNS1) was recalculated to be 25 days. This was compared to the BCS1 duration of 33 days, the difference was 8 days delay due to the EN delays in snapshot 1, as shown in

Fig. 3.33. After that the excusable compensable delays were excluded from the BCS1 schedule, a new schedule (BES1) duration was calculated to result in 31 days duration. Comparing this to the BCS1 duration, gave a delay of 2 days due to the EC delays in the first snapshot period (Fig. 3.34). The sum of the EC and the EN were adjusted to be equivalent to the total delays for which the owner was responsible during the first snapshot, these were found previously to be 9.78 days or 10 days, thus in this case 8 + 2 = 10 days, this means that no adjustment was needed.

8. The same procedure was applied to the second snapshot BCS2, where the EN delays were excluded from that schedule to get BNS2 schedule with a duration of 36 days. Comparing this with the BCS2 schedule duration of 41 days, a 5 days delay for the second snapshot period was encountered (Fig. 3.35). Likewise, by excluding the EC delays from the BCS2 schedule resulted in 41 days duration for BES2 schedule (Fig.3.36), thus there was no effect due to the EC delays within snapshot 2. Analyzing the owner's delays within that period the summation of the results, i.e., (5 + 0 = 5), is 2 days less than the total delays for which the owner is responsible which was found to be 7 days. Therefore a ratio adjustment was required:

[(5/5) * 2] + 5 = 7 days delay due to EN delays in snapshot 2.

[(0/5) * 2] + 0 = 0 day, no delay due to EC delays in snapshot 2.

9. Summing the results: the EN delays in the first period were 8 days, adding them to the EN delays of the second period of 7 days, resulted in 15 days EN delays, for which the owner was responsible, and for which the contractor is entitled to time extension. The EC delays in the first period were 2 days, and none in the second period. So the owner is liable to the contractor for 2 days, for which the contractor was entitled to claim for

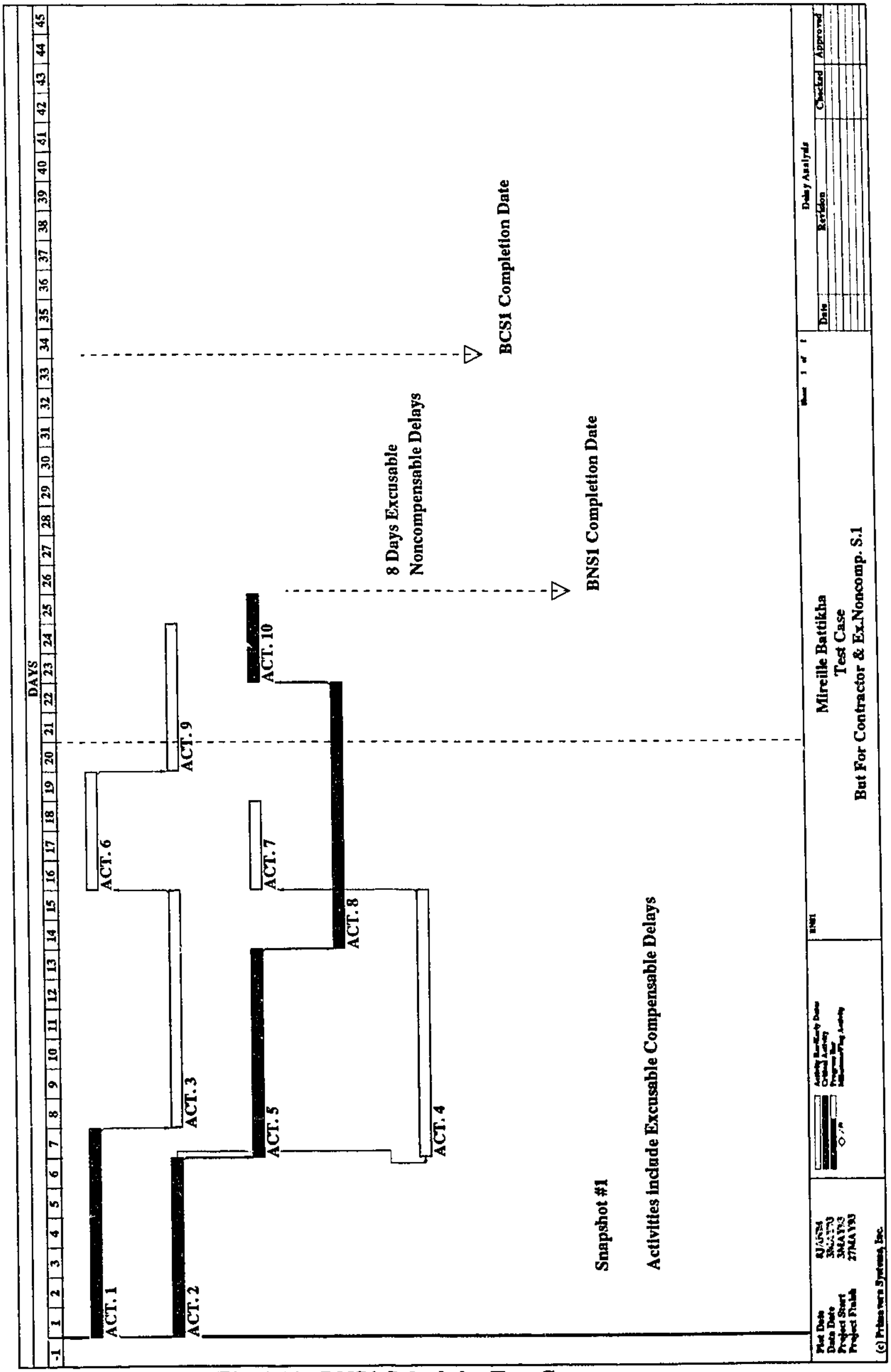

Fig. 3.33. BNS1 Schedule; Test Case

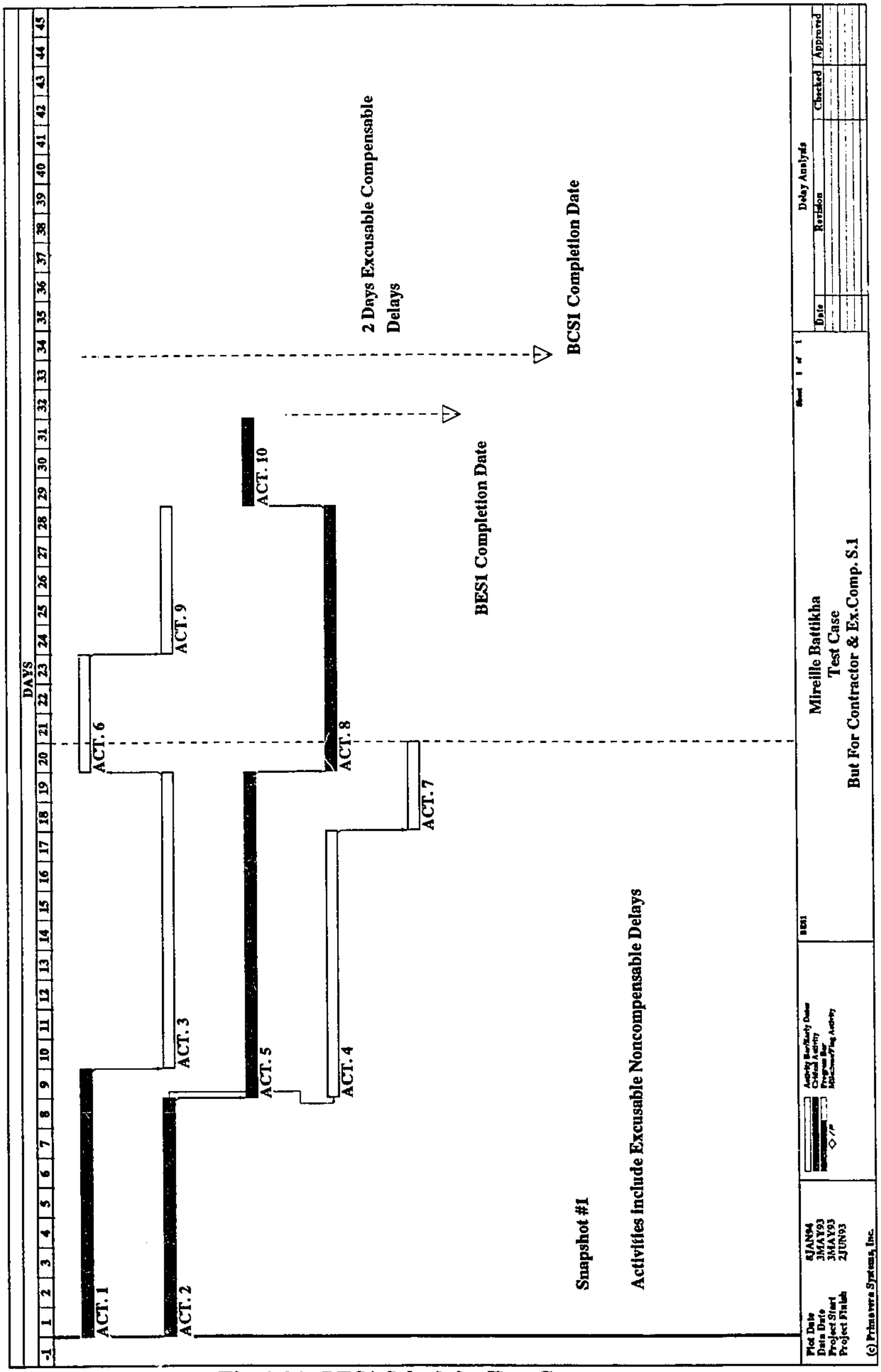

Fig. 3.34. BES1 Schedule; Test Case

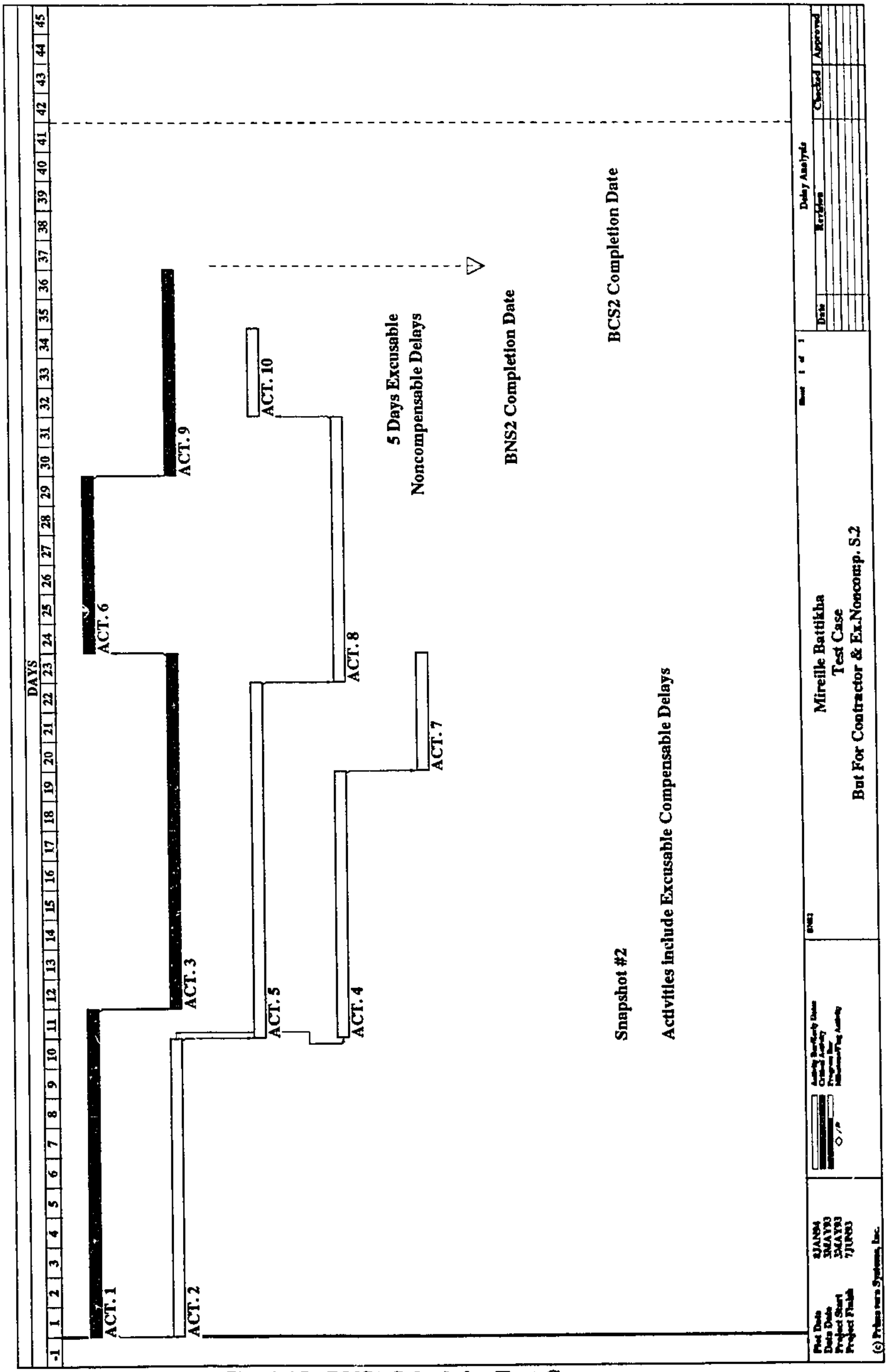

Fig. 3.35. BNS2 Schedule; Test Case

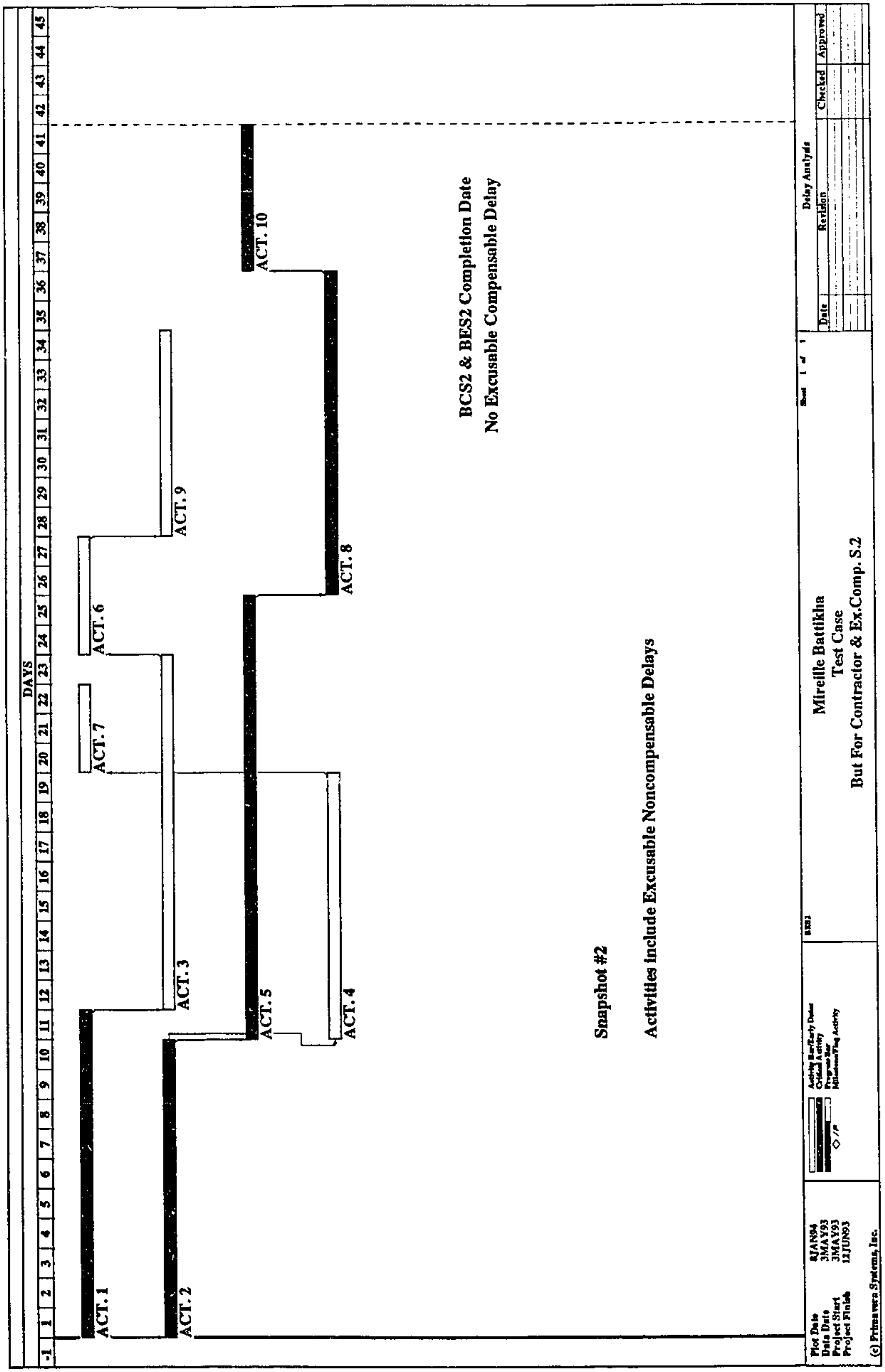

Fig. 3.36. BES2 Schedule; Test Case

granted time extension and extra costs. Likewise the owner was entitled to claim liquidated damages for 1 day NE delay, for which the contractor is liable, as agreed upon in the contract.

3.6 Advantages of the Proposed Delay Analysis Technique

1. Concurrent delays are analyzed and adjusted, to overcome the problem of overstatement of time extension requested for.

2. The analysis is performed within time periods (snapshots) to carry a systematic and dynamic analysis of delays, focusing on their causes, while carrying the analysis using delays in their real context of time and critical path.

3. The delays are scrutinized according to their types before the analysis and incorporated periodically into the schedule.

4. An adjustment ratio is used to correct the overstated or understated amount of delays. This ratio is applied in each corresponding period and not at the total delays, to ensure more accurate results.

5. The analysis can be performed using any time period at any stage of the schedule. Delays can be added to the original schedule or removed from the actual one while performing the analysis as long as consistency is kept for facilitating the presentation. In addition, the analysis can be performed in a forward or a backward manner. It can also be done only for a certain window through the schedule, or carried out with ongoing delays.

6. The technique mainly uses the as-built schedule rather than the as-planned schedule, because the as-built schedule reflects the events as they happened in the reality. Also it

is more likely that at the time of the analysis, an as-built schedule is more available than an as-planned schedule. By removing one party's delays from the as-built schedule and comparing the schedule durations, in order to calculate the liability, is more advantageous than comparing with an as planned schedule, since the CPM of the as-built is a real one. Moreover, the effect of the combined effect of both parties' delays is shown in the as-built, and the extraction of one party's delays will show how much these delays were impacting the schedule and how they affected the critical path.

7. Both parties are given the chance to consume the float, and each with its own delays, that is when performing the analysis for each party individually.

8. The amount of compensable delays is determined, which is the basis for costs calculations, thus providing an easier and faster procedure for calculating damages.

9. The analysis is objective, since it is done for both parties at the same time, be it used for asserting or defending against a claim.

10. The whole analysis can be performed within an integrated computer environment, utilizing database/spreadsheet, expert system, and project management software, as will be demonstrated later in the computer integrated system for delay analysis. The analysis is effective in reducing time and cost for claims preparation.

3.7 Conclusion

One cannot detect change without having a benchmark by which to measure it. Delay can be measured against the original project schedule. A realistic detailed schedule is not only an important management tool but it is essential in detecting and proving delay or suspension. Full daily reports from the field are required and an as-built schedule should be maintained. A deviation indicates a potential claim, and early identification will enable the contractor to properly document his claim and file the required notification.

Analyzing the current delay analysis techniques and assessing their results using a test case, their advantages and shortcomings were identified, and a new delay analysis technique was introduced and described. The proposed technique was tested using the same test case in order to compare its results to the assessed techniques. This new technique proved to have a lot of advantages, and outperformed the other techniques. Its outcome could be used to quantify impact costs as discussed in the coming chapter. In addition the proposed technique is accommodated within the computer integrated system, that is described in chapter five.

CHAPTER IV

QUANTIFICATION OF IMPACT COSTS DUE TO COMPENSABLE DELAYS

4.1 Introduction

In all construction claims, there are two major issues which must be overcome before resolution can occur; entitlement and quantification. Whenever entitlement for construction delay claims has been approved, there might be compensation. Since both the owner and the contractor are involved, two kinds of compensations are required; first, the owner is entitled to liquidated damages when the contractor has been in fault for the delay. This amount usually per day is determined from the contract language which has been previously agreed upon. Second, when the owner is responsible for the delay, the contractor is entitled to claim for time extension, and extra costs incurred due to compensable delays, including direct, indirect, overhead, and impact costs.

Productivity-related impact costs are those resulting from reduction or loss of productivity. These costs can rarely be established accurately, simply because it is difficult to demonstrate what costs would have been incurred without the inefficiency. This chapter addresses the quantification of impact costs related to productivity loss due to compensable delays. It covers an assessment of the existing methods for quantifying impact costs, and focuses on describing a new methodology for calculating such costs.

4.2 Loss of Productivity

In general, productivity measures the efficiency with which resources (inputs) are utilized in producing goods and/or services (outputs). Productivity in construction represents the performance efficiency of human and/or equipment resources (Ta[illegible] et al. 1981). Measurement of labour productivity can be attempted in several ways, varying from activity sampling to time-lapse photography, or interviews with field personnel (Borcherding et al. 1980). In construction, productivity is usually taken to mean labour productivity, that is, units of work placed or produced per man-hour (Halligan et al. 1994). This measure of productivity has several advantages: the meaning of the term labour productivity is relatively well understood; labour productivity is often the greatest source of variation in overall construction productivity; and the productivity of other inputs can often be measured with respect to labour productivity (Halligan et al. 1994). The inverse of labour productivity, man-hours per unit (unit rate), is also commonly used. A variety of related productivity measures have been developed (Thomas et al. 1990), however, the choice of a particular measurement depends on the purpose for which it is used.

Productivity is a measure of output over input, a measure of efficiency (Jergeas et al. 1993). Any impediments to progress lead to a reduction in efficiency, consequently to a reduction in output, or work produced, relative to input and hence an increase in cost per unit of work produced. There are many factors which must be present for efficiency to be attained on a construction site. These include: consistent management direction and effectiveness; availability of working details or conditions prior to setup; access to the work on hand and its continuous availability; as well as human factors relating to work crew motivation and attitude (Jergeas et al. 1993).

Although productivity is often thought of as relating solely to labour, in practice it relates to any resources used to produce a result, such as labour, equipment, materials, energy, and capital. Since labour constitutes a large part of the construction cost and the quantity of labour-hours in performing a task in construction is more susceptible to the influence of management than are materials or capital, this productivity measure is often referred to as labour productivity (Hendrickson et al. 1989). However, it is important to note that labour productivity is a measure of the overall effectiveness of an operating system in utilizing labour, equipment, and capital to convert labour efforts into useful output and is not a measure of the capabilities of labour alone (Hendrickson et al. 1989). Construction output may be expressed in terms of functional units or constant dollars, and the input, in terms of labour hours (Hendrickson et al. 1989).

For the purpose of this work, productivity is defined as labour productivity, units of work accomplished per man-hour. In the literature, the term productivity is often used interchangeably with the term efficiency. In keeping with this convention, no distinction has been made between productivity and efficiency. The present research work focuses on evaluating loss of productivity that might take place due to delays or disruptions of construction projects. Accordingly, loss of productivity can be defined as the decline in labour efficiency due to specific causes from the level which could have been achieved except for the cause(s) under examination. In other words, a loss of productivity is the difference between the productivity actually observed and the productivity that might reasonably have been expected if not for the condition in question. Two steps are required to evaluate a loss of productivity. First, it must be demonstrated that a loss occurred. The second step is to determine what event(s) caused the loss, that is to establish cause and effect (Halligan et al. 1994).

To quantify loss of productivity, measurements are usually made at the micro level of a project as most causes of impact affect the rate at which labour performs specific tasks or groups of tasks (labour efficiency) and not the contractor's entire method of operation or macro level (labour effectiveness). In this research productivity is referred to at the micro level with respect to labour.

4.3 Effects of Delays and Disruptions on Efficiency

Research has shown that the major contributors to productivity-related problems in construction are not related directly to the worker such as attitude or motivation. Instead, the biggest contributors to productivity problems are those that are controlled by management or are caused by outside influences (Aaron et al. 1990). Labour productivity can vary significantly depending on several factors:

. Environmental effects: like weather conditions, job conditions, and site conditions.

. Human factors: the skill and efficiency in performing tasks improve with repetition and this observation has led to the development of "learning curves" (Barrie et al. 1978). The size of projects, delays, disruptions, all of which influence productivity negatively (Borcherding 1975, Thomas 1991).

. Management factors: morale, safety, incentives, design changes, overtime, inadequate planning and scheduling, etc. (Taner et al. 1981).

Productivity losses decrease as the routine-acquiring of the operation increases. The loss of productivity depends greatly upon the learning curve, and the length of interruption (Frantzolas 1984). The "learning curve effect" is taken into consideration in the variations of productivity. The learning curve effect refers to the gradual increase in productivity that occurs as workers become more familiar with job conditions and as methods and organization of the job are refined (Moselhi et al. 1991). However, only for the operations exhibiting productivity improvement prior to the interruption, did productivity start at a much lower rate than when interruption occurred. No productivity loss was recorded for any operation not exhibiting productivity improvement. Thus, the review of the work progress reports can provide very useful information, which is a guide to evaluate the additional costs resulting from the decreased productivity (Frantzolas 1984).

Productivity improvement results from the mutual influence of the following factors (Frantzolas 1984):

1. Skill acquired through the execution of the operation;
2. Expertise;
3. Better management, improvement of coordination; and,
4. Benefits resulting from the operation's momentum.

In a complex repetitive operation, the first two factors contribute more to productivity improvement whereas in a simple repetitive operation the last two variables play a more significant role in productivity improvement. The length of the interruption affects these two factors. A short term interruption immediately affects the last two factors and only as the interruption becomes more extensive that the adverse effects begin to impact significantly the first two factors (Frantzolas 1984). Thus, continuity of work is required in order to achieve productivity in the construction work environment. The two major factors affecting labour productivity requirements are the organizational continuity, and the executional continuity. Organizational continuity relates to work that needs to be done and encompasses physical components of work, specification requirements, design details, and so forth. It is called the work content. Executional continuity relates to work environment and how well a job is organized and managed. Management aspects include weather, material and equipment availability, congestion, and out-of-sequence work (Thomas et al. 1994).

The effects of variations in the work and/or changes in the period of performance may reduce the efficiency of the labour force or disrupt the sequence of performance and cause substantial extra costs to be incurred (Richter 1977). Inefficiency and disruption may appear in a variety of circumstances, including but not limited to: congested work areas; interferences of different trades; extra shifts; overmanning; unfavourable work conditions; excessive demobilization and remobilization; lack of continuity of operations; adverse weather; and, inability to schedule effectively (Richter 1977).

Change orders represent one of the major factors that contribute in loss of productivity

(Fazio et al. 1984). Change order work can result in planned and unplanned disruptions. A planned disruption is one which is recognized and integrated into the work progress schedule before the changed work performance starts. An unplanned disruption is one that is not foreseen, not scheduled, and usually not as well documented as a consequence. Work performed out-of-sequence, whether planned or not, mitigated or not, can result in increased production costs, which may be compensable (Richter 1977). Change orders events disrupt and delay performance of affected activities and often those indirectly affected resulting in loss of productivity (Leonard 1988). These events may result in delays and disruptions which affect the learning curve effect, by inducing stop and go operations, and out-of-sequence work.

There are many factors that may lead to a loss of productivity, and many of these factors may interact to cause a loss, while their impact varies from project to project, from activity to activity, and from crew to crew. In all the causes of impacts, the major factors contributing to a loss of productivity are related to delays and disruptions (Thomas et al. 1994).

Proving losses of efficiency is usually a difficult task that often requires an analysis based on the judgement of an expert rather than the data provided by an accountant. Factors which contribute to loss of productivity often occur concurrently. Segregating the costs associated with each factor is usually very difficult if not impossible (Richter 1977). Sometimes a factor is used for eliminating the delay not attributable to the owner because there was insufficient information concerning actual extra costs due to loss of productivity through disruption of the schedule, idle labour and equipment, and extra direct, indirect, and overhead costs (Richter 1977).

In computing the costs of inefficiency, percentages of loss of productivity are often used. Proving this rate of loss is a difficult task that often results in attempts to set bargaining rather than real rates. The reality of proof of loss of efficiency is that unless documentation is so exact that the rate of loss jumps off the paper, one will be unable to even determine the rate, much less prove it. Thus, what is required is not proof of the rate of inefficiency, but rather several methods of substantiating the rate of loss. Seldom is one method alone convincing. Support of causation coupled with the substantiation by alternate methods has proven compelling in a number of cases. Proof of costs and the ability to recover extra costs in work is dependent to a very great extent upon convincing that the costs have been incurred, thus documentation of actual costs is favoured.

4.4 Assessment of Existing Methods for Quantifying Impact Costs

Calculating loss of productivity due to delays is required to quantify the extra costs incurred due to the impact. Several methods are currently used to calculate the productivity losses including the Total Cost Method, the Differential Cost method, or the Statistical Charts.

The total cost method provides an inaccurate way of computing the impact costs, and is used after the fact, that is after the impact had occurred. The difference of the actual and the estimated costs is the basis for calculation, which does not segregate the effects due to the compensable delays, thus the owner will be paying an overestimated amount. Owners and courts of law do not look favourably upon the total cost approach because it does not take into account contractors' inefficiencies assumed by them under the contract. Still with the modified total cost method, the same problems of inaccuracy are encountered, even with the modification adjusted on the estimate, the results are not accurate. This method is the least preferred by courts in calculating the productivity loss.

The differential method, the measured mile approach, and the revenue per workhour approach, where a comparison is done between an impacted period and an unhindered period, are also carried out after the fact, where their use for estimating the impact costs during the course of the project or beforehand cannot be performed. Moreover, they require certain conditions including the availability of detailed accurate data on physical progress and labour hours. In addition a period of normal productivity is required for comparison, that may not be available on many projects. Even when these are provided the actual productivity is not a true measure of the effects of the compensable delays alone but to the total factors that existed during that period, and which may not be the owner's fault. It has been found that 60% of the projects could not accommodate the application of the differential method (Leonard 1988). However, the differential cost method is the mostly preferred one in courts.

Statistical charts, such as those prepared by NECA (1969; 1974), MECA (1976), US Army Corps of Engineers (1979), Business Roundtable (1980), Revay and Associates (Brunies 1988), and Mathews Curve (Heather 1989), are also used to estimate impact costs. Most of these charts are empirically derived (Moselhi et al. 1990). "Mathews Curve" analysis is that, if changes have accelerated, delayed, or disrupted a project, the percentage of delay has affected the costs by a corresponding amount on the curve. The analysis is done on the activity level, and some conditions for critical path activities have to be met. The estimation includes the percentage of increases in direct costs. It also considers the total amount of time caused by all types of delays, and not for compensable delays only, thus, a further analysis to the costs for adjusting the results. The effect of acceleration on delay is taken concurrently and not as cumulative effect, in other words the loss of efficiency would not be assessed for both the delay and the acceleration and then added together. This method has been criticized as being unrealistic since it considers the contractor's estimate for a base efficiency. Moreover if the method is applied after the fact there is a tendency to view the analysis as Total Cost, especially if the bid estimate is used as the basis for the original cost, it is suggested that an independent cost estimate be utilized (Heather 1989). This method has many constraints to be taken care of for the validity of its application (Heather 1989).

The study carried out to quantify loss of productivity due to change orders (Leonard 1988, Moselhi et al. 1991), with one or two major causes of impact, on building and industrial projects, for electrical/mechanical contracts, and civil/architectural contracts, provides an estimation of productivity loss in cases where change orders cumulative workhours exceed 10% of earned cumulative contract hours. However, this study estimates the productivity loss caused by change orders which do not necessarily incur delays, in case of an acceleration, or a change in the design. In addition, this measure of cumulative hours does not reflect the magnitude a schedule time impact.

A knowledge-based approach has been used to quantify impact costs (Nicholas 1989). The productivity-related impact costs are calculated at the activity level, based on the productivity factors generated by the system and later combined to account for the impact of more than one factor (Moselhi et al. 1990). Using the statistical charts for calculating the productivity loss due to several factors, then adding the effects of these factors, might yield erroneous results. In the sense that, adding several factors percentages, might result in a total of more than 100% loss of productivity.

A linear relation was found to exist at the activity level between the length of delay or interruption and efficiency, proving that the longer the delay, the less efficiency is performed (Thomas et al. 1990, Thomas 1991). In addition, other researchers (Revay 1990) suggested that productivity loss could be calculated as a percentage of the delayed activity duration using a proportional ratio, that is the extended duration of the activity will be inversely proportional to the loss of productivity. This method is performed at the activity level and assumes that the time extension is due to the productivity loss.

4.5 Productivity Loss and Compensable Delays

The main purpose for evaluating the loss of productivity is to calculate the damages caused by the owner's delays, and specifically the compensable ones. Only loss of productivity due to such delays, entitle the contractor to compensation. However, the literature lacks information on an existing methodology in relating the loss of productivity to compensable delays. Therefore, it is beneficial to study the effect of compensable delays on loss of productivity and to try to establish a relationship between them. In other words, a new methodology to quantify impact costs related to productivity loss caused by compensable delays need to be introduced (Battikha et al. 1994b). This need is based upon the following reasons:

. To overcome the limitations of the existing methods.

. To develop an alternative method to estimate productivity loss when other methods fail to apply.

. The need to evaluate the productivity loss due to only compensable delays, without the effect of other impacts due to contractor's fault, acceleration, or other unrelated causes of impacts.

. To establish a link between the compensable delays determined by the previously described delay analysis technique, and the calculation of loss of productivity due to these delays, for a fast assessment of the impact.

. The productivity loss to be found is computed from the cumulative effect of the factors that contributed in that loss, which are only due to compensable delays. Thus no further analysis would be required to deduct the costs of the numerous factors affecting adversely productivity, and which are not caused by compensable delays.

. To study the effect of compensable delays on the overall project completion duration and not on the individual activity duration.

. To provide a simple and fast procedure to be accommodated in the integrated system, in order to effectively calculate the delayed time and its related costs.

4.6 Methodology of Analysis

To examine the effects of compensable delays on productivity, a "case study" approach was adopted. Information for the study was obtained from construction management consulting firms in Canada and USA, specializing in construction disputes. The data was collected on 130 cases, among which, 90 were adopted from the literature (Leonard 1988), whereas the 40 remaining cases were acquired directly from consulting firms, by correspondance or by searching through existing claim files. These reports contained contractors' claims, claims evaluations, and expert reports prepared by the firm. The cases were drawn from projects carried out in Canada and the USA, within the last 15 years. These projects comprise various types of buildings and industrial facilities, including electrical, mechanical, civil, and architectural work.

To account for the variances in productivity losses due to the type of construction, the type of impact, and the duration of the project, the cases were segregated and the appropriate ones were selected according to the following criteria:

1. Only data from building projects were considered, industrial projects were disregarded, since productivity in industrial construction depends greatly on the types of machines to be fixed, rather than on the construction procedure.
2. Only projects with an original duration of more than six months were considered, in order to examine projects with considerable duration, since this factor affects productivity (Thomas 1991).
3. Only projects that have undergone compensable delays with no other kind of delays or impacts that were not the owner's fault, were considered.

4. Acceleration is considered as an impact that is not a compensable delay, while its effect hinders the real measurement of delays. Hence accelerated projects were disregarded. However, the loss of productivity due to acceleration could be added, if required, and the impact could be estimated from Mathews Curve (Heather 1989).

Only 38 cases were found to be suitable for this work, and were examined for the regression analysis. The description of these selected cases is provided in two tables. Table 4.1, exhibits data related to the cases selected from previous documentation (Leonard 1988), and Table 4.2, illustrates data related to the cases selected from the collected ones, by correspondance and searching through existing claim reports. The description of the useful cases include: the type of project, the original contract value, the project original duration, actual duration, size of delays, percentage loss of productivity, and percentage extended duration of the project.

4.7 Variables of the Model

Delays affect the continuity of work, hence the learning curve effect, and consequently the productivity is reduced. To examine the statistical relationship between compensable delays and loss of productivity, it was necessary to ensure that the causes of productivity loss were attributed to those delays. Normally, it is difficult to accurately identify and evaluate causes of productivity loss. Consequently, it was necessary to examine the project history of each of the cases, the related analyses carried out by the previous documentation, and the claims analyses of the cases collected from the consulting firms. This included productivity analyses, comparisons of as-planned and as-built projects

Table 4.1. Data Related to Selected Projects for the Analysis
(Ref. Leonard 1988)

Type of project	Value of contract ($)	Original duration (days)	Actual duration (days)	Size of delays (days)	Extended duration (%)	Productivity loss (%)
1 Health Centre	537,000	360	820	460	127	30
2 Office Complex	NA	510	810	300	59	18
3 Office Complex	NA	510	810	300	59	12
4 School	460,000	180	300	120	65	14
5 Hospital	1,450,000	360	660	300	83	24
6 Office Building	1,070,000	180	270	90	50	10
7 Airport Terminal	1,751,000	270	480	210	76	31
8 Airport Terminal	815,000	420	840	420	100	22
9 Airport Terminal	2,878,000	390	570	180	46	15
10 Hospital	5,000,000	720	960	240	33	11
11 Educational Residence	1,310,000	180	420	240	133	26
12 Educational Residence	2,000,000	360	450	90	25	14
13 Educational Residence	NA	360	450	90	25	18
14 Educational Residence	260,000	180	300	120	67	24
15 Educational Residence	430,000	180	330	150	83	19

Table 4.2. Data Related to Selected Projects for the Analysis
(collected from industry)

Type of project	Value of contract ($)	Original duration (days)	Actual duration (days)	Size of delays (days)	Extended duration (%)	Productivity loss (%)
16 Office Complex	1,703,200	300	630	330	110	19
17 Residential	NA	230	411	181	79	23
18 Residential	17,247,247	393	546	153	39	16
19 Residential	3,739,760	416	536	120	29	19
20 School	12,457,856	403	536	133	33	16
21 School	1,006,916	180	479	299	166	32
22 Residential	2,692,211	365	526	161	44	21
23 Residential	2,855,627	190	555	365	192	32
24 Residential	3,850,656	179	470	291	162	24
25 School	1,022,833	190	440	250	131	28
26 Office Complex	650,000	180	249	69	38	23
27 Office Complex	6,908,900	210	510	300	142	31
28 Office Complex	1,460,000	450	563	113	25	16
29 Office Complex	3,083,200	600	966	366	61	24
30 Office Complex	29,726,000	270	386	116	43	20
31 Residential	2,078,965	180	315	135	75	29
32 Office Complex	NA	180	220	40	22	17
33 Office Complex	NA	240	255	15	6	14
34 Office Complex	70,000,000	660	693	33	5	10
35 School	8,393,200	450	509	59	13	16
36 Hotel	NA	450	567	117	26	18
37 Museum	1,100,000	480	600	120	25	19
38 Office Complex	8,424,189	360	480	120	33	21

schedules durations, and causes of impacts. Following the previous criteria for the selection of projects, the appropriate ones were chosen accordingly.

For the purpose of quantifying compensable delays, the following two measurements were considered:

[1] Size = (as-built duration) - (as-planned duration)

In other words the size of compensable delays is the amount of time the total project duration has been extended due to the effect of compensable delays upon the schedule. It represents the net time impact on the total schedule duration, caused by the compensable delays.

[2] Percentage = (size / as-planned duration) * 100

The percentage represents the percentage extended duration of the project impacted by the compensable delays, relative to the original project duration.

For each of the cases examined the measurement of size and percentage extended project duration due to compensable delays was calculated, and were considered each separately as an independent variable. Each of these two measurements was statistically examined separately with the dependent variable, which was expressed as percentage loss of productivity.

Calculations of loss of productivity presented in the literature (Leonard 1988), as well as the analyses of the remaining cases, were considered reliable for the purpose of this study.

Productivity loss was calculated in most of the cases, using the differential cost method, and whenever unproductive hours were associated with the contractor's inefficiency, an adjustment was performed, including the consideration of the site factor. The site factor is a measure of the accuracy of the contractor's estimate for the original scope of work, [earned (normal) / estimated hours]. Based on a ratio of output to input, the productivity index attained by the contractor on the original scope of work is calculated as the ratio of the normal hours to the actual contract hours. The unproductive labour-hours attributable to the compensable delays under examination, expressed as a percentage of labour-hours spent on original contract work, is referred to herein as percentage loss of productivity, and calculated as follows:

[3] Percentage Productivity Loss = (1 - PI) * 100

where PI is productivity index. Data on productivity loss for the cases under examination are presented in both tables 4.1 and 4.2.

4.8 Results of Analysis

To examine the relationship between compensable delays and loss of productivity, a statistical analysis was performed on the data from the 38 selected cases. The method of least squares or regression analysis was used to check the dependency of productivity on compensable delays. A commercially available software package was utilized to carry out the regression analysis (Statgraphics 1989).

4.8.1 Regression of compensable delay measurements

The statistical relation was examined first, between the percentage loss of productivity as the dependent variable, and the size of the compensable delays, and second between the productivity loss and the percentage of extended project duration due to compensable delays. To determine which, if any, of the compensable delays measurements, size or percentage, correlates better with percentage loss of productivity as the dependent variable, a linear regression analysis was performed. The value of correlation coefficient for regression of percentage loss of productivity on percentage project extended duration due to compensable delays yielded higher and stronger correlation than that of the size of compensable delays. This indicated a poor correlation, with a coefficient of correlation value of 0.54, compared with the strong value of 0.76. The variable chosen for a better correlation was the percentage extended duration of the project due to compensable delays.

4.8.2 Rejection of outlier points

Residuals of the linear regression of percentage loss of productivity on percentage compensable delays were reviewed to identify outlier points, (points that lie more than three or four standard deviations from the mean of the residuals) (Draper et al. 1980). Upon careful examination of the related cases, only two outlier points were identified. The cases were rejected because the impact resulted in an unusually large loss of productivity, compared to other cases exhibiting the same percentage of delay.

4.8.3 Linear versus nonlinear regression

Following the rejection of outlier, linear and nonlinear (polynomial, logarithmic, and exponential) regression analyses were performed for the selected cases. The results indicated that the coefficient of correlation value of 0.76, was greater for the linear than the nonlinear regression models. For the polynomial of the second, third and fourth order, the regression yielded coefficients of correlation values of 0.76 as well. In the logarithmic and exponential regressions the coefficients of correlation were 0.69 and 0.70 respectively. However, the standard error of estimate was the least in the linear regression with a value of 4.174, compared with the other values of 4.214, 4.275, 4.339, for the polynomial regressions of the second, third and fourth order, respectively. The standard error of estimate was not calculated for the logarithmic and exponential regressions since the values of the coefficients of correlation were smaller than the coefficient of correlation value of the linear regression. Accordingly, the linear regression model was adopted to describe the relationship between the effect of compensable delays and loss of productivity, which is illustrated in Fig. 4.1. Since this model provided the best goodness of fit. A line will have a good fit, if it minimizes the error between the estimated points on the line and the actual observed points that were used to draw it (Levin 1981). Although there are no similar studies to enable direct comparison with the findings of this study, it is important to note that previous related studies established linear and near-linear relationships (Leonard 1988, Moselhi et al. 1991, Heather 1989, Thomas et al. 1990). This indicates that the linear relationship is compatible with the previous work and with the other causes of productivity loss, such as overmanning (Department of the Army 1979), scheduled overtime (NECA 1969). The model under examination resulted in the following linear regression equation:

[4] $Y = 13.8585 + 0.0986X$

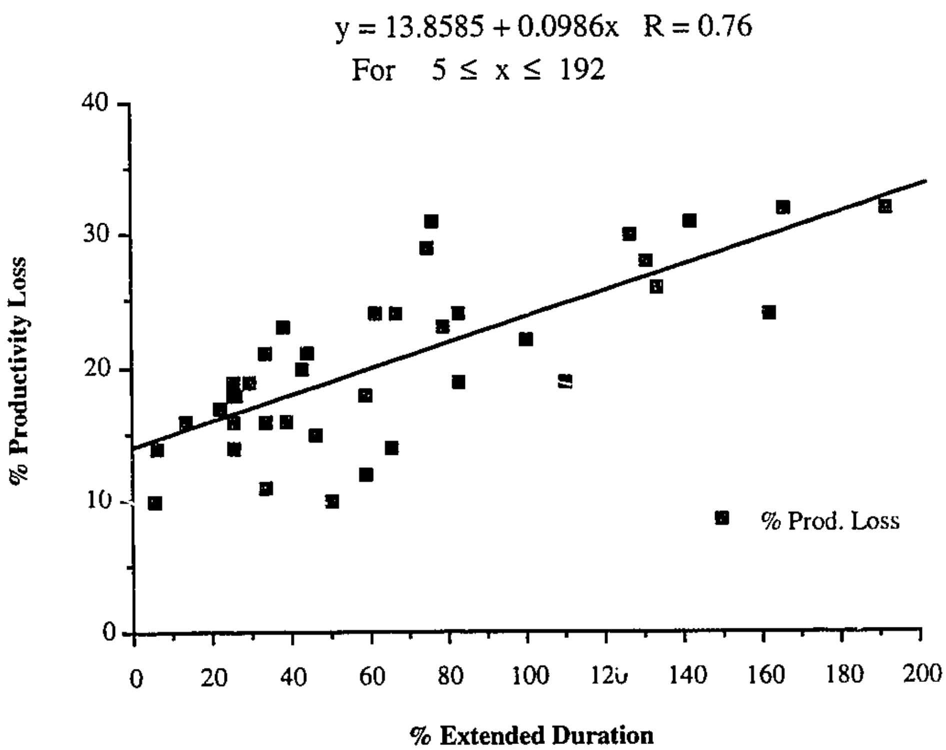

Fig. 4.1. Effect of Compensable Delays on Productivity Loss

4.8.4 Coefficient of correlation

To check the estimating equation, it is required to verify its accuracy, and its reliability. Accuracy is verified by the mathematical properties of a line fitted by the method of least squares, that is the individual positive and negative errors must sum to zero. To measure the reliability of the estimating equation, the standard error of estimate is used to measure dispersion. The standard error of estimate measures the variability or scatter, of the observed values around the regression line (Levin 1981).

Correlation analysis is the statistical tool that we can use to describe the degree to which one variable is linearly related to another. Statisticians have developed two measures for describing the correlation between two variables: the coefficient of determination symbolized by $\mathbf{R}^2$, and the coefficient of correlation denoted by $\mathbf{R}$, which is the square root of the coefficient of determination. The higher the coefficient of correlation the stronger the relationship, and the sign of $\mathbf{R}$ indicates the direction of the relationship between the two variables. As can be noted from Fig. 4.1, the coefficient of correlation between the percentage extended duration of the project due to compensable delays and percentage loss of productivity was 0.76. Considering the nature of these variables, such a coefficient indicates a significant correlation. The standard error of estimate was 4.174, indicating that the equation of the relationship is reliable.

4.8.5 Conditions, scope, and limits

The conditions applied to the selected cases represent the limitations and the scope of applicability of the regression equation. It applies to building projects, with original project duration not less than six months, and where the net effect of the compensable delays on the project duration could be identified and quantified.

Linearity cannot be assumed beyond the limits of the data, and often not even as far as that when the limit is represented by a single case (Beeston 1983). Accordingly the data indicate the lower limit in the percentage project extended duration due to compensable delays as 5%, and the upper limit as 192%, thus, limiting the application of the regression equation to these values. In addition, if the model is tested for a zero compensable delay, the productivity loss would be about 14%, thus being taken within the contractor's contingencies. Results for productivity loss do not usually start from a zero value, since there is up to 15% productivity loss in most of the projects, due to personal factors of labor, fatigue, and delay allowances, taken as contingencies for the contractor, and which could be absorbed (Ostwald 1992, McDonald 1992).

Similar to industry-wide studies, the present model also yields averages. Accordingly, there might be situations resulting in different values of productivity loss than those estimated with the developed model, if quantified with the differential method. However, such deviations are not more pronounced than those of other industry-wide statistics charts which are commonly used to estimate loss of productivity. A relation was established between the percentage of the project extended duration due to compensable delays, and the percentage of productivity loss. This was found for cases on various building projects, involving electrical/mechanical, and civil/architectural contracts.

4.9 Advantages and Practicality of the Proposed Methodology

The proposed methodology offers some advantages and practicality in its use, mainly as follows:

1. Real construction projects were used as samples for determining the relationship of the productivity loss, and the extended duration of the project. Those projects were analyzed, and the productivity loss was determined for most of the projects, using the differential method which is the mostly preferred in courts. Thus the relationship is mainly representative in its estimation for the differential method.
2. Cost and time effective, since it is performed in a fast and easy way, and there is no need for data comparisons, normal periods, or other conditions.
3. Links directly to the amount of compensable delays, thus avoiding the deduction of the losses caused by other impacts or by the contractor.
4. Integrates with the delay analysis technique proposed in the previous chapter.
5. Could be accommodated within a computer integrated system, that will be described in the coming chapter.
6. Estimates costs of delays beforehand or during the fact, which helps analysts and managers anticipate extra costs, extra manpower, and provide corrective measures.
7. Provides extra information in risk analysis for claims.
8. Gives warning to avoid delays and to take corrective action when possible.
9. Could be used by contractors in preparing claims for additional compensation and by owners in evaluating contractors' claims, at any time during or after the project life.
10. Could be used when other estimating methods to calculate productivity loss due to compensable delays, fail to apply.

Although predictions obtained from this model are averages which do not account for the specific circumstances of a particular project, it is well established in courts of law that precise calculation of loss of productivity is not essential for recovery (Wunderlich Contracting Co.). It is important to know that courts do, however, require strict proof of causation between cause and effect. Therefore, the results obtained from the developed model, as with any other industry averages, ought to be supported by expert analysis of the specific facts that establish causation (Moselhi et. al 1991). However the previously proposed delay analysis technique, which determines the amount of compensable delays is, in other words, providing the cause and effect.

4.10 Conclusion

Impact costs related to productivity loss are difficult to quantify, and several methods have been utilized to estimate those costs. However, these methods are not accurate and do not apply to most of the circumstances. Therefore, a new approach has been proposed to quantify the productivity loss due to the extended duration of the project impacted by the compensable delays, since these delays are considered to be the basis for costs compensations. A linear regression model was examined for this purpose. The results of the correlation analysis showed a confident relationship between the percentage of the extended duration of the schedule due to compensable delays, and the percentage of the productivity loss. Thus, costs calculations could be performed and accommodated within the computer integrated system for claims delay analysis, that will be discussed in the next chapter.

CHAPTER V

THE PROPOSED COMPUTER INTEGRATED SYSTEM FOR CLAIMS DELAY ANALYSIS

5.1 Introduction

A construction project is one example of an engineering system, where there is a great deal of data. Managing a construction process in itself is a challenging assignment that cannot be performed effectively and successfully without a good information system to deal with the data and, subsequently, the knowledge that is extracted from the data (Rasdorf et al. 1992). Thus the demands for contemporary and valid information make computer applications in the industry appealing to most companies. Computers are used literally for everything these days. They represent the new high technology, and are a powerful tool having the capability of converting raw data into useful information quickly and expeditiously, since they get data, process it, and deliver it.

In an attempt to improve the process of claims delay analysis, the incorporation of the computer into the process is undeniably one of the most significant recent developments. Proposing an integrated computer-based system to facilitate the process of claims delay analysis and their preparation, is the focus of this chapter. The proposed system which is called Claims Delay Analysis and Impact Costs calculation (CDAIC), (Battikha et al. 1994b), comprises the integration of existing management software tools such as:

database/spreadsheet, project management, and expert system. It will minimize effectively the time and cost of preparing claims.

5.2 The Proposed Integrated System (CDAIC)

The use of computers for claims administration is a relatively new development. The 1970's brought widespread computerization to many medium to large construction firms. The end of the 70's marked the beginning of a microcomputer revolution. This revolution is continuing and computerization is taking place more rapidly, not only for estimating, scheduling and accounting but for change order administration and claim support as well (Kraiem 1984).

One of the primary goals of any well-designed integrated system is to operate as easily and efficiently as possible to generate the desired information (Parfitt et al. 1993). A modern software is first designed to be a stand-alone module rather than a component in an integrated system. An integrated system such as CDAIC, therefore, requires meshing of the individual application packages around a shared information core that must resolve any conflicting data conventions.

CDAIC is designed to provide three main key functions, mainly: the project track, the delay analysis, and the impact costs quantification, as shown in Fig. 5.1. The user at the start will input data about activities and delays, and after carrying on with the key functions, will be able to present output results about time and cost entitlement to each party. The user will be able to present the analysis using graphics representation and

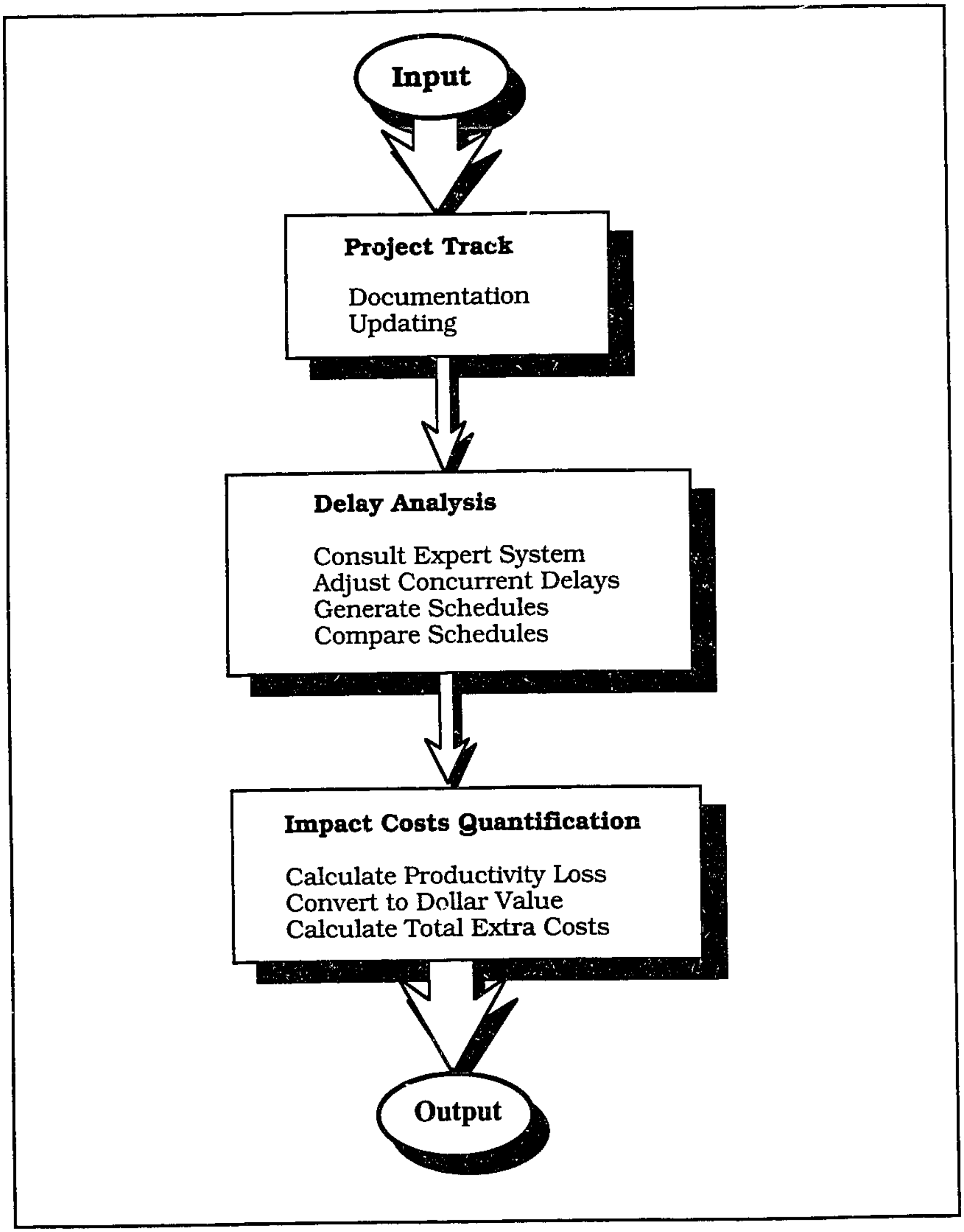

Fig. 5.1. The CDAIC Key Functions

reports. The whole system for claims preparation will reduce the time and cost of preparing the claim by a substantial amount. This is true, even in the case where a manual rather than a computerized system is used for recording data. However, the computerized system can be made to work much more effectively and more rapidly, and the retrieval of data may be made much more efficiently. Increased computing power has meant that quite sophisticated data flows may be obtained as long as the data are input in accordance with a logical system. The system must be as comprehensive as possible within the limits of its storage and retrieval capabilities. The CDAIC is designed to assist management teams and claims analysts, be it with the owner's or contractor's organization involved in construction projects, in the analysis of claims arising from delays.

Before discussing all the steps performed in the proposed system, it is necessary to provide a short description of the capability of each software used in the integrated system, and the function of each component, as described in the CDAIC architecture (Fig. 5.2). The application programs employed by the system are currently available for commercial use by the construction industry, and include: dBASE IV (1992); Lotus 1-2-3 (1991); Primavera (1991); and VP-expert (1989).

5.2.1 The Expert System (Delay Advisor)

Expert Systems are computer programs which use knowledge obtained from experienced practitioners (experts) in a specific domain, to assist others (users) in solving complex problems at expert level of competence (Kostem et al. 1986). Expert systems trace their beginnings to the mid 1960s and are a class of AI (Artificial Intelligence) systems. A well

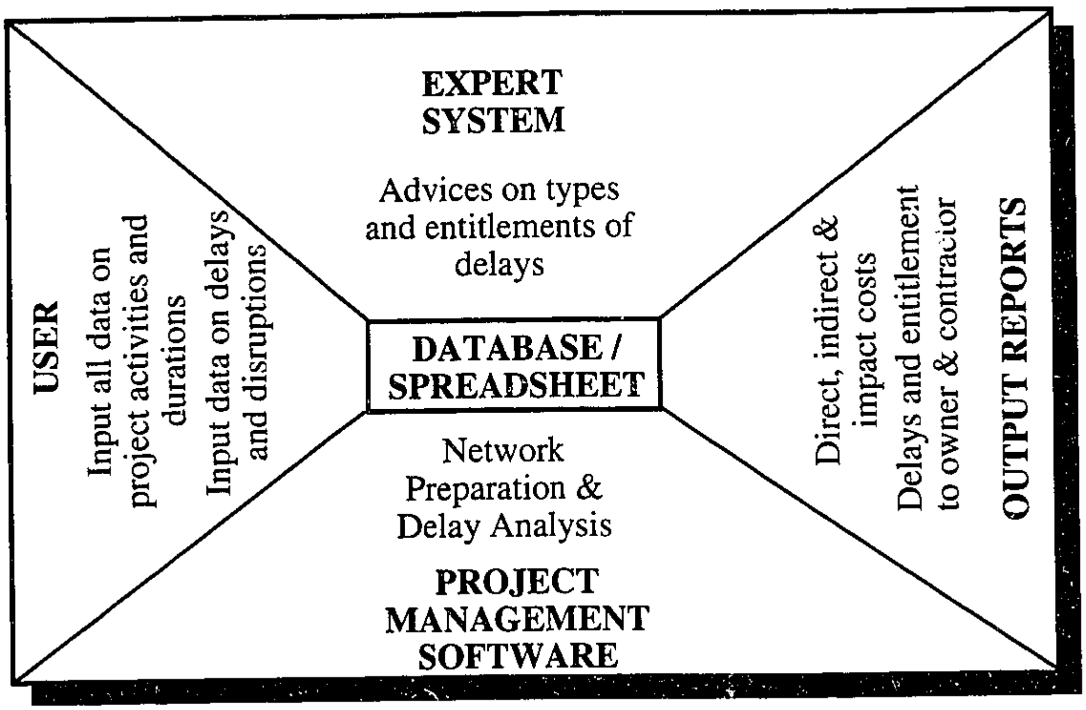

Fig. 5.2. The CDAIC Architecture

designed expert system is able to act as an intelligent agent or expert consultant. It gains its abilities from two major components: (1) A knowledge base, which is a collection of facts and heuristics regarding a specific domain or area of expertise; and (2) an inference mechanism which directs the manipulation of the knowledge base according to a set of rules for applying the knowledge (Diekmann et al. 1984). Expert systems which have been developed span a variety of disciplines ranging from medicine to chemistry, from law to geology.

Expert systems and their applications to the construction industry in general (Kostem et al. 1986), have been successfully applied to claims analysis (Diekmann et al. 1984, Cobb 1986, Alkass et al. 1987, Kraiem 1988, Kraiem et al. 1988, Riad et al. 1989, Diekmann et al. 1990). However, expert systems are not a total substitute for experts, but do help to conserve expertise and are used to make expertise more widely, easily, and quickly available for assistance in the decision-making process in claims analysis.

A Knowledge Based Expert System (Delay Advisor), directed towards analyzing the types of delays, such as, nonexcusable (NE), excusable noncompensable (EN), and excusable compensable (EC), is used in the proposed integrated system as one of its components. The KBES has been integrated within the CDAIC system, by an interface with the database management software. Information about type of delays (i.e., NE, EN, or EC), and their entitlement, be it time extension, extra costs, or both, are decided upon by the expert system and exported to the database. The KBES contains knowledge about construction delays arranged in the form of if-then rules, thus enabling the system to advise the user on the type of delay in question in a short period of time.

5.2.2 The Database/Spreadsheet

One of the problems associated with conducting a claim delay analysis, is the meticulous sorting through piles of project documentation to sort and ascertain pertinent delays encountered during the project (Alkass et al. 1993). Project documentation such as letters, minutes of meetings, notes, materials receipts, supervision and inspection reports, resources data and costs, play an important role in preparing claims. Unfortunately, the varied and often diverse sources for this information present the claims analyst with a difficult task in preparing an accurate delay 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 is recommended to be implemented to store information on each delay as it occurs. This information could include: delay type, description of delay, who is responsible, delay code number, date of occurence, letters/notes sent and received including dates, resources used and their costs. The advantage of keeping record of this information when the delays occur becomes evident at a later date, when information is easily retrieved and organized. The main attribute of systematically keeping track of delays when they occur 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 piles of project documentation to put together an account of events. In the event that a claim analysis is required, a large part of the data gathering aspect is already complete. This alone can reduce cost and time associated with a claim analysis.

In a claim delay analysis the file containing all the delayed activities can be sorted and delays grouped in a manner suited for the analysis with the capabilities of the database management system. Sorting information about delays and activities, organizing them according to many factors or criteria, and storing that information to allow export/import from/to other software, is the major function of the dBASE component. It works as the nucleus core function that is capable of organizing and storing data to be exported, updated, and imported to and from the other software (i.e., project management, and expert system).

The same function can be done using a spreadsheet format. This would be more advantageous when great amount of cost calculations are involved. Spreadsheets are capable of calculating the costs of delays, using the previously generated formulae for impact costs quantification, as well as the direct, indirect, and overhead costs, where Lotus 1-2-3 was used for that purpose.

5.2.3 The Project Management

The project management component involves the use of a project management software that is capable of exporting and importing project information to and from external database/spreadsheet. The project management software enables activities to be scheduled in the CPM format, in addition to other capabilities such as: activities relationship types, resources and resource levelling, costing, calendars, data manipulation, reports, and graphical representation. For this purpose and for availability reasons, Primavera (1991) was utilized to generate the different schedules required to perform the delay analysis. The capability of exporting and importing files from and to this software, in addition to organizing and selecting activities within those files according to several criteria, are essential in order to generate the required schedules.

5.2.4 The User

The user's role is to gather and input data in dBASE or Lotus software, on activities and delays including, activities durations, start and finish dates, relationships, resources costs, delays durations start and end date of delays, cause of delays, etc. Comparing schedules, producing reasoned reports for time and cost entitlements is another task of the user.

5.3 The Integration Process

The integration process is explained by a flow chart, shown in Fig. 5.3. It is designed to provide three major functions to perform the analysis: the project track, the delay analysis, and the impact costs quantification. The system functions with the database/spreadsheet as a centralized or nucleus component.

5.3.1 Project track

This function is split into two categories; first documenting the data about activities and delays, for organizing pertinent information and setting the as-planned schedule; second, updating the project's progress schedule in order to determine the as-built schedule.

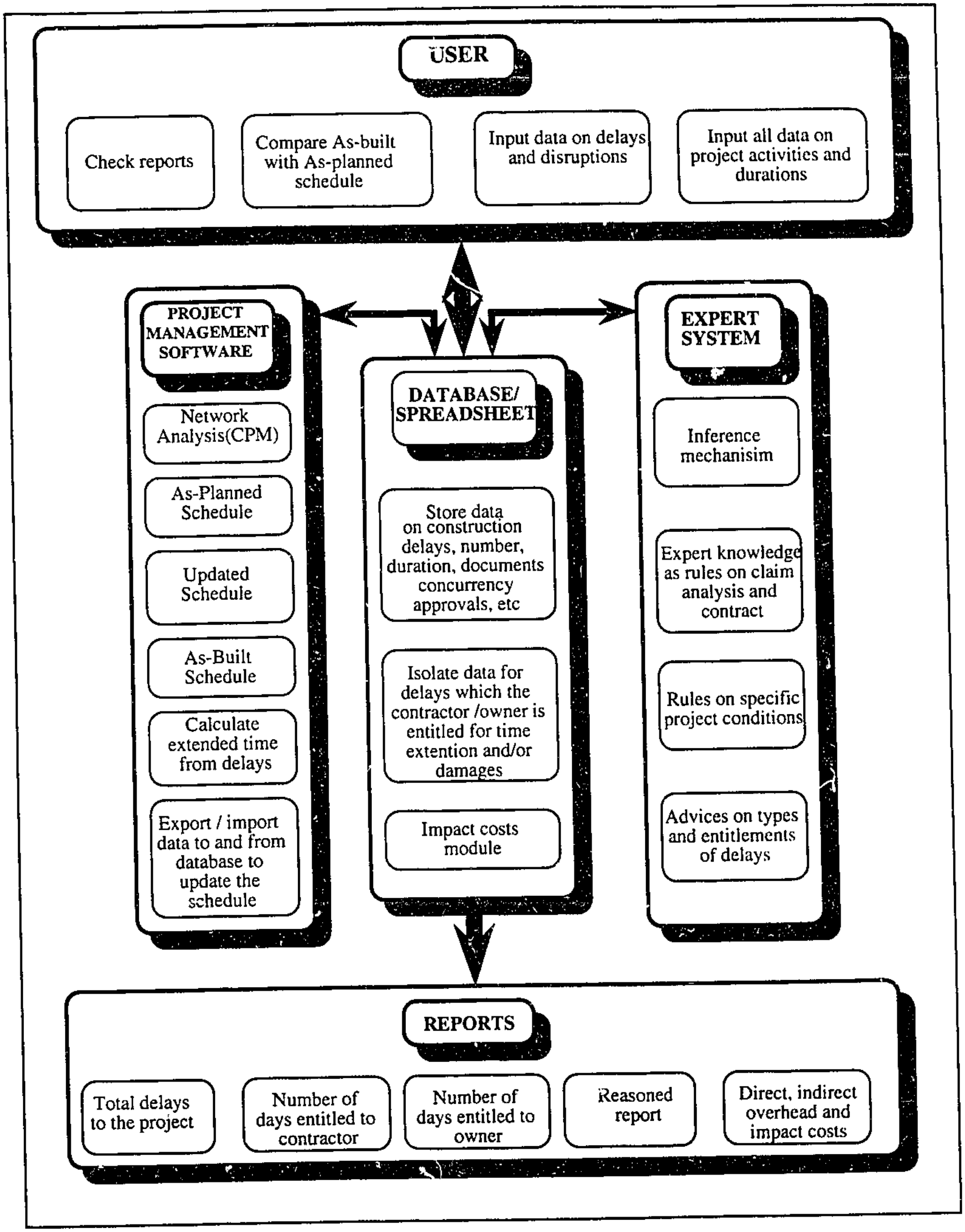

Fig. 5.3. The CDAIC Integration Flow Chart

i) Documentation

This part is performed by the user by collecting information on project activities and delays, during or after the construction phase. Information is collected from project description, letters, meetings, notes, correspondance, and other documents. Pertinent data on activities and delays are stored in the dBASE/Lotus, including activities durations, relationships, start and finish dates, floats, and related resources costs. Similarly, data on delays are stored, such as date of delay, duration, start and end date, reasons or facts, responsibility, and related resources costs, etc. Useful data are organized in a way required to perform schedule analyses. From the available data on the project activities, a realistic as-planned schedule is established, if not available from the contract documents. In addition, the actual data on activities are used to determine an as-built schedule.

ii) Updating

An as-built schedule is required to calculate the time variance of the project duration. If an as-planned is not available, an as-built schedule could be established from actual data on the activities and delays, and then by eliminating all delays, an as-planned schedule is generated. However, an as-planned schedule can be useful to start and track the project duration by updating it during or after the construction period, thus determining progress schedules during the construction phase, at different intervals of time. In order to do so, the project management software is used, in conjunction with the database management.

Updating the as-planned schedule requires several steps. Setting up the as-planned schedule focuses on establishing a realistic schedule. Considering that as a start, when available, the following are the steps performed to update the as-planned schedule:

1. Within the project management software, isolate activities within the selected time period. Using the content window of the export file, containing the relevant items about the activities, identify the pertinent items to be exported, such as activity ID, start and finish dates, original duration, remaining duration, total float, Log, etc.

2. Export the file previously mentioned, to the dBASE software using the export capability of the Primavera software. Adjust within the dBASE, the remaining duration of each delayed activity within the selected time period. In other words, the original remaining duration is increased to account for the delay encountered. This increase in time of the remaining duration is the amount of delay that the activity has suffered. Store all files in dBASE, before and after adjustments, in order to keep records of all variances. Fig. 5.4, exhibits an updated dBASE file to be imported to Primavera. It contains the relevant items of the delayed activities within the first time period of the case study described in chapter six.

3. Import the adjusted file from dBASE to Primavera, using the import capabilities of the Primavera, in order to update the schedule.

4. Recalculate the project duration, after maintaining a duplicate of the file before updating, using Primavera scheduling capability. The generated schedule includes all delays encountered within the selected time period. This adjusted schedule for that selected time period serves as the base schedule to generate the next adjusted schedule for the following time period update.

5. Repeat the previous steps for the remaining time periods selected during the project duration. The last generated schedule is the actual or as-built schedule, it includes the

```
ACT     S00
TITLE   Structure - Parking
ES      08/08/89
ESA
EF      09/22/89
EFA
AS        /  /
AF        /  /
TF           0
OD          34
RD          80
LOG1    House not removed until 17Aug89; 8 days EC
LOG2    Bldg. permit not issued until 6Sep89; 21 days EC
LOG3    Downed crane; 3 days NE
LOG4    Repair shear wall; 1 day NE
LOG5    Rain; 4 days EN
LOG6    Added length to form and pour work; 4 days EC
LOG7    Change orders #23, 33; 5 days EC

ACT     M01
TITLE   Mechanical - Ground Floor
ES      09/25/89
ESA
EF      10/13/89
EFA
AS        /  /
AF        /  /
TF          62
OD          15
RD          21
LOG1    Delays in mechanical installations; 6 days NE
LOG2
LOG3
LOG4
LOG5
LOG6
LOG7

ACT     S01
TITLE   Structure - Ground Floor
ES      09/25/89
ESA
EF      10/13/89
EFA
AS        /  /
AF        /  /
TF           0
OD          15
RD          28
LOG1    High wind; 2 days EN
LOG2    Rain; 4 days EN
LOG3    Heavy snow; 3 days EN
LOG4    Added length to form and pour work; 4 days EC
LOG5
LOG6
LOG7
```

Fig. 5.4. Updated dBASE File for First Time Period

```
ACT     S02
TITLE   Structure - 2nd Floor
ES      10/16/89
ESA
EF      11/03/89
EFA
AS        /  /
AF        /  /
TF          0
OD        15
RD        36
LOG1    Downed crane; 1 day NE
LOG2    Heavy snow; 3 days EN
LOG3    Added length to form and pour work; 9 days EC
LOG4    Change orders #36, 37; 8 days EC
LOG5
LOG6
LOG7
```

Fig. 5.4. Updated dBASE File for First Time Period (continued)

actual events and delays that the project encountered during its construction.

From these generated schedules within selected time periods, the proposed delay analysis technique can be applied as described in the next function. However, if an as-planned schedule was not available the delay analysis can be performed using the as-built schedule.

5.3.2 Delay analysis

To perform the delay analysis that was proposed in chapter three, several schedules are required in order to calculate the effect of each type of delay on the project's completion date. In order to determine the amount of time that is entitled to each party, several tasks are required to be performed, which are described in the following steps:

i) Consult expert system (Delay Advisor)

Assessing the causes and classifying the type of a delay is complex, requiring careful judgement executed by very experienced practitioners. In this context, the expert system (Delay Advisor) can help in determining the type of a delay and its entitlement. It is structured in a manner that facilitates the user to steer through a step-by-step process. It helps by bringing together as many strands of expertise as possible.

Developing the expert system is not within the scope of the present work, however, a prepared expert system is linked to the dBASE, by using its export/import capabilities. Thus delays information could be evaluated using the expert system at any time a delay is recorded. This evaluation is saved in the dBASE file containing the useful information about activities and delays. Therefore, delays are classified and identified according to their type, as nonexcusable (NE), excusable noncompensable (EN), or excusable compensable (EC).

ii) Adjust concurrent delays

To identify the type of each delay in the schedule, special care is taken in determining the entitlement of concurrent delays. Delays are considered to be concurrent when they simultaneously occur on critical paths of the as-built schedule. In such a case, these delays are identified and sorted in the dBASE by date and activity total float. After consulting the expert system about their initial entitlement, their adjusted entitlement depends on their concurrent status: i.e., if an excusable noncompensable delay occur at the same time with an excusable compensable or with a nonexcusable delay, then the excusable compensable and/or the nonexcusable delay would change to an excusable noncompensable delay. Also, if an excusable compensable and a nonexcusable delay happen concurrently, then both types would change to an excusable noncompensable delay. The adjusted type of concurrent delays is stored in the dBASE with the other pertinent delay data, in order to be used in the schedule analyses.

iii) Generate schedules

With the organized useful data, the as-built schedule, and the adjusted schedules performed for selected time periods, in the updating phase, the schedules required to apply the delay analysis technique are generated. Each updated schedule containing all delays during the selected time periods, is used to generate further schedules, by excluding each of the types of delays from that schedule, be it NE, EN, or EC. This is done using Primavera and dBASE export/import. It is important at this stage to keep duplicates of data and schedules before and after altering the durations.

iv) Compare schedules

To determine the amount of time that each party's delays affected the total project duration, schedules are compared and ratio adjustments are applied as described in chapter three.

5.3.3 Impact costs quantification

Productivity-related impact costs are calculated using the equation described in chapter four. The direct, indirect, and overhead costs would be added to these impact costs, in order to determine the total extra costs, as follows:

i) Calculate productivity loss

The amount of time that the compensable delays have impacted the project duration determined in the delay analysis, is calculated as a percentage of the original project duration in a spreadsheet. This percentage is induced in the established regression equation, and the corresponding percentage loss of productivity is calculated.

ii) Convert to dollar value

The percentage loss of productivity is multiplied by the actual manhours used to accomplish the project. This amount of hours is converted into monetary value by multiplying it, by the average labor hour cost in dollars. This is calculated and stored in a spreadsheet format.

iii) Calculate total extra costs

The direct, indirect, and overhead costs are calculated using the spreadsheet capabilities, and then added to the impact cost due to loss of productivity, which generate the total extra costs caused by the compensable delays.

5.4 The Integration Process in Summary

1. Collect and store in a database/spreadsheet, information on delays during the project construction phase.
2. Isolate delayed activities within the project management software.
3. Export data on these activities to database/spreadsheet.
4. Consult the expert system to classify types of delays.
5. Adjust the entitlement of concurrent delays within the database.
6. Update the schedule and perform schedule comparisons within specific time periods.
7. Repeat steps 1 through 6 for each chosen period to determine the total delayed time due to each party.
8. Export the extended duration of the project due to compensable delays, to spreadsheet to calculate its percentage increase and the corresponding loss of productivity and impact costs.

5.5 Advantages of the Integrated System

1. The system uses several well-known computer application programs that are currently used by the construction industry, therefore, no additional costs are incurred in purchasing the software. It is usually the case that the contractors and managers are familiar with the software used in this system, hence, no training is required to learn it.
2. The advantage of an integrated environment is the potential of the system to reuse and transfer data.
3. The system accommodates a delay analysis technique and a cost quantification methodology to estimate impact costs. Hence, it simplifies otherwise complicated procedures currently used in industry.
4. The proposed system facilitates the process of preparing claims analyses, thus saving time and money.
5. Data could be stored in order to be reused at any time for different purposes, thus avoiding sifting through documents.
6. The analysis can be presented in a clear and precise way, including reports and graphs, since they are done within a computerized environment.
7. The analysis can be performed by practitioners or any analyst not involved in the dispute, thus, providing objective and persuasive results.
8. The system could help owners, contractors, and managers perform analyses before, or during the fact, thus, anticipating possible problems, and arranging for possible corrective measures.
9. The process provides a simple way to analyze delay claims and allows access to information about causes of delays, thus, contributing in claim avoidance measures.

10. Savings are evident even if the only benefit is avoiding multiple data input on the same event. In addition, it permits more flexibility in creating and storing individual project information.

11. Information and reports derived from interrelated data can be quickly and easily generated to suit individual user requirements and take advantage of historical information from past projects.

12. The system can be set to function at any stage as long as information is available.

13. The system is flexible to the extent that it allows to calculate impact costs for compensable delays already calculated elsewhere, or perform a delay analysis using types of delays categorized by an analyst without the use of the expert system. Therefore, the proposed system is flexible enough to accommodate the needs of the user.

5.6 Conclusion

Present methods of preparing delay claims are time consuming and costly. A large portion of effort in preparing these claims arise from the meticulous digging through piles of project documentation to sort pertinent data. The process is usually difficult due to the lack of documented information. The proposed system indicates that a database management system of stored and organized documentation can reduce cost and time associated with claims analysis. The components of the system involve: the user, database/spreadsheet, project management software, and an expert system. CDAIC is designed to provide three main key functions: project track, delay analysis, and impact costs quantification. It uses the export/import capabilities of project management software and expert system, as well as the manipulation of data within the database or spreadsheet applications, while the expert system advises on type and entitlement of delays. The system would assist practitioners in saving both time and money in preparing claims delay analyses.

CHAPTER VI

SYSTEM VALIDATION: A CASE STUDY

6.1 Introduction

Verification and validation, are the necessary and sufficient conditions for having evaluated a system (Satre et al. 1991). Verification is defined, as an area of validation with the distinction being that verification is concerned with whether the system operates correctly and validation whether the system is correct or appropriate for the problem to be solved (Finlay et al. 1988). Other sources of definitions for verification and validation exist elsewhere (IEEE 1983, Geissman et al. 1988). "Geissman and Schultz stated that "Verification is a determination that software has been developed in a formally correct manner in accordance with a specified software engineering methodology." They define validation for expert systems as the "...ensuring that the expert system satisfies its users' needs."

The objective of this chapter is to validate the effectiveness of the proposed computer integrated system for delay analysis (CDAIC), using a real case study. The case consists of a construction project which has had a delay analysis already performed. This served the purpose of comparing results. However the scope of the delay analysis that was already performed, was limited to determining the effect of delays on the project in time only, utilizing the But For (Collapse) delay analysis technique.

6.2 The Case Study

CDAIC was evaluated using a case study that was adopted from the industry. The case involved a construction project of a 15 storey residential tower. It was selected because it experienced various types of delays which were reasonably well laid out, and it had a delay analysis already performed. The source of information used in this case study is kept unrevealed for the purpose of confidentiality.

The contractual duration reflected in the as-planned schedule was 254 working days at a cost of $8,366,000. The project was planned to start on August 8, 1989, and have the work completed by August 7, 1990. During the course of its construction, the project encountered several delays which led to an extension to its completion date. This extension to the original duration totalled 193 working days, thus resulting in an as-built duration of 447 working days, and the project was actually completed in May 15, 1991. As a result, the contractor filed a lawsuit to get compensated for monies lost due to the project overrun.

The case study consists of 84 activities broken up into six major areas: structural, mechanical, electrical, exterior brick and windows, elevators, and miscellaneous finishes. An as-planned schedule was provided as shown in Fig. 6.1. It was used to start the project track and delay analysis, with the use of the information about the delaying events that were documented in the claim report. Those delays have already been classified, into excusable compensable (EC), excusable noncompensable (EN), and nonexcusable (NE), and were grouped into three categories: i) Owner's failure to provide unrestricted access

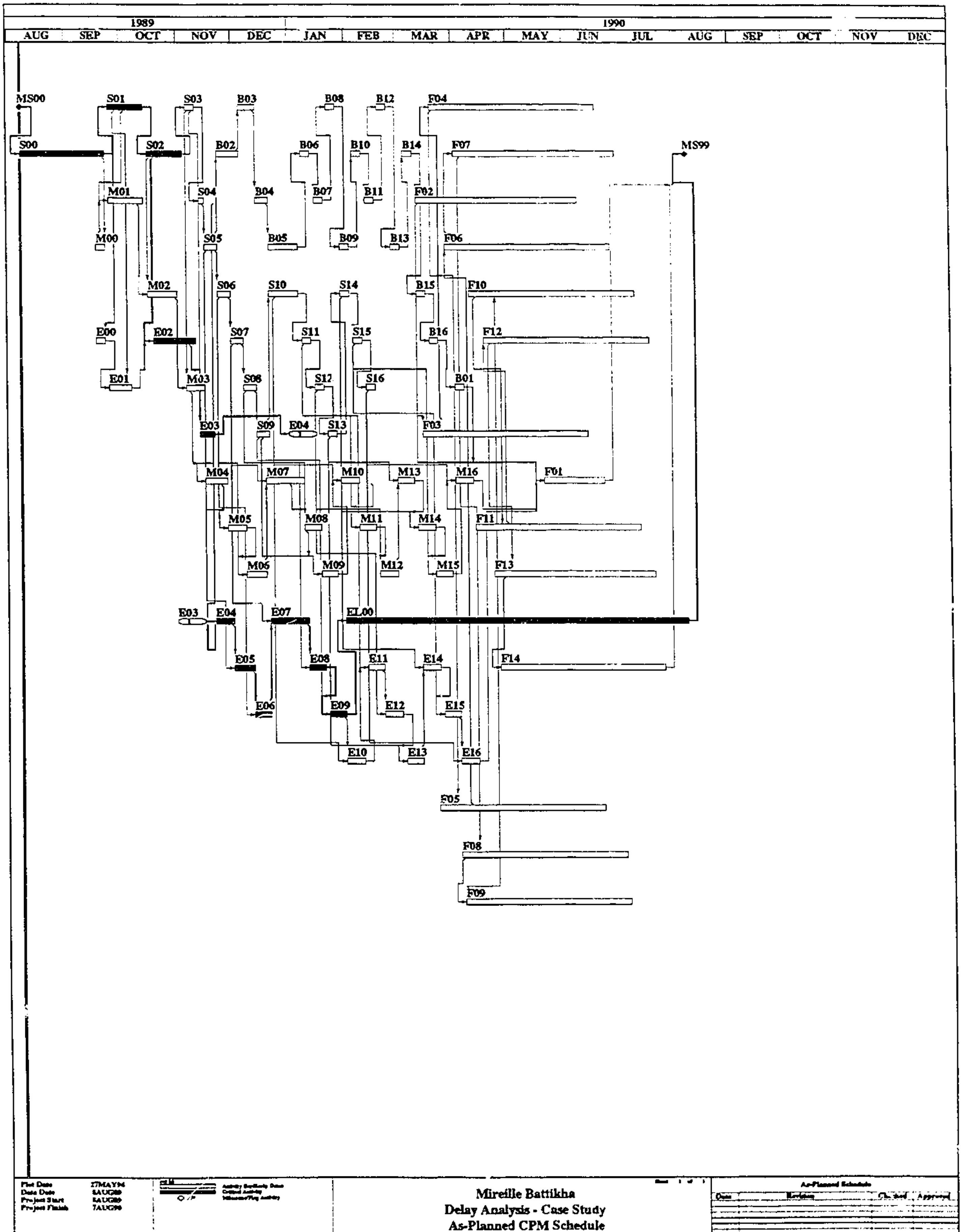

Fig. 6.1. As-Planned CPM Schedule; Case Study

to work areas; ii) Inordinate amount of site instructions and change orders; and iii) Other delays, as per the claims report.

6.2.1 Delays description

The following is a brief description of the delays considered for the case study:

i) Owner's failure to provide unrestricted access to work areas.

1. The house was not removed from site until 17 August 1989 (8 days EC).
2. The building permit (foundations only) was not issued until 6 September 1989 (21 days EC).
3. Encroachment agreement with the East side of the project was not obtained until 26 September 1989 (used up float).
4. Extra work; piling for West side to get clear access; completed 19 October 1989 (used up float).

As a result of the above owner's delays, inclement weather was encountered and caused initial structural work to experience extreme delays in the following:

1. Parking structure;
2. Form and strip ground floor;
3. Second floor.

ii) Inordinate amount of site instructions and change orders

The architect issued approximately 198 site instructions, 155 contemplated change orders, and 91 change orders which include more than 880 changes, over a 17 month period.

Only 76 days were deemed excusable compensable, as per the claims report. The following is a list of change orders (CO) used in the case study:

1. CO #23; 2 days
2. CO #33; 3 days
3. CO #36; 3 days
4. CO #37; 5 days
5. CO #39; 10 days
6. CO #41; 3 days
7. CO #42; 1 day
8. CO #44; 1 day
9. CO #45; 1 day
10. CO #46; 1 day
11. CO #47; 1 day
12. CO #52; 14 days
13. CO #53; 14 days
14. CO #54; 4 days
15. CO #55; 1 day
16. CO #57; 2 days
17. CO #62; 1 day
18. CO #63; 1 day
19. CO #66; 2 days
20. CO #67; 1 day
21. CO #70; 1 day

22. CO #76; 1 day

23. CO #77; 1 day

24. CO #78; 0.5 days

25. CO #86; 1 day

26. CO #87; 0.5 days

iii) Other delays

More delays had affected the completion of the work, which were experienced by the contractor, such as:

1. Delays to the structure described as follows;
   a) rain and high wind (crane); 13 days EN
   b) added length of form and pour second floor task (design change); 17 days EC
   c) heavy snow; 6 days EN
   d) trucker strike; 14 days EN
   e) waiting for design changes; 28 days EC
   f) downed crane time; 15 days NE
   g) repair shear wall; 1 day NE
2. Delays to pouring over radiant heat; 7 days EN
3. Electrical rough-in and other work to penthouse suite; 30 days EC
4. Delays to balcony railing; 10 days EC
5. Design conflicts; 20 days EC
6. Delays in mechanical installations; 6 days NE
7. Delays in electrical installations; 1 day NE

8. Delays in installing elevators; 17 days NE

6.2.2 Activities and their related delays

The delayed activities are listed in a chronological order with their associated cause, duration, and type of delays as follows:

Activity S00;

. House not removed until 17 August 1989; 8 days EC

. Building permit not issued until 6 September 1989; 21 days EC

. Downed Crane; 3 days NE

. Repair Shear Wall; 1 day NE

. Rain; 4 days EN

. Added length to form and pour work; 4 days EC

. Change orders #23, 33; 5 days EC

Activity M01

. Delays in mechanical installations; 6 days NE

Activity S01

. High wind; 2 days EN

. Rain; 4 days EN

. Heavy snow; 3 days EN

. Added length to form and pour work; 4 days EC

Activity S02

. Downed crane; 1 day NE

. Heavy snow; 3 days EN

. Added length to form and pour work; 9 days EC

. Change orders #36, 37; 8 days EC

Activity S03

. Trucker strike; 14 days EN

. Rain; 3 days EN

. Downed crane; 11 days NE

. Wait for design changes/clarifications; 28 days EC

Activity E03

. Change order #39, 41, 42, 44, 45, 46, 47; 18 days EC

Activity E04

. Change orders #52, 55, 57, 62, 63, 66, 67, 70, 76, 77; 43 days EC

. Delays in electrical installations; 1 day NE

Activity EL00

. Change orders #78, 86, 87; 2 days EC

. Delays in installing elevators; 17 days NE

Activity F02

. Abnormal weather, topping over radiant heat; 7 days EN

Activity F03

. Design change, delay in delivery of railing; 10 days EC

Activity F04

. Design conflicts; 20 days EC

Activity E16

. Design change, electrical rough-in and other work to penthouse suite; 30 days EC

Although the selected case study had a lot of relevant delay information, some documentation on key issues were missing, therefore, certain assumptions were made they were:

i) The method of construction remained constant throughout the construction phase.

ii) Changes were not made to the durations and/or relationships of activities.

6.3 Project Track; Case Study

The true application of the system would be used with an on-going project, keeping track of the project and delays as they occur. Upon completion of the project, all the analysis could have been accomplished. Since this was not possible because the project was completed, the documented information from the claim report of the case study was used.

6.3.1 Documentation

The project data from the case study was used to re-enact the tracking of the project. The as-planned schedule was available to start with, as illustrated in Fig. 6.1, in addition to the pertinent data about the delays. From a duplicated as-planned schedule in Primavera, an export file was prepared, the relevant items to be documented and updated were chosen from the content window (i.e., activity ID, activity title, early start, early finish, actual start, actual finish, total float, original duration, remaining duration, and log records for free comments), then activities were sorted in chronological order (using the sorting capability of Primavera). Thereafter, the file was exported to dBASE, in order to input pertinent information about the actual delaying events. This step was performed at regular intervals or time periods of the project duration. Fig. 6.2 and Fig. 6.3, illustrate dBASE files containing updated data for the second and third time periods respectively, whereas the first time period dBASE file was shown in Fig. 5.4. Three periods were chosen for this case study, which extended from: 8 August 1989 till 30 April 1990; 1 May 1990 till 31 December 1990; and 1 January till 15 May 1991, for the first second and third time periods respectively.

6.3.2 Updating

At each time period, after documenting the information about the delaying events associated with their related activities, the remaining duration of each delayed activity was changed to include the duration of the delay (Fig. 5.4, Fig. 6.2, Fig. 6.3). The updated report in dBASE was imported to Primavera and the schedule was recalculated to determine an adjusted completion date. It should be noted that a stored file was kept in

```
ACT     S03
TITLE   Structure - 3rd Floor
ES      03/07/90
ESA
EF      03/13/90
EFA
AS        /  /
AF        /  /
TF          0
OD         5
RD        61
LOG1    Trucker strike; 14 days EN
LOG2    Rain; 3 days EN
LOG3    Downed crane; 11 days NE
LOG4    Wait for design changes/clarif.; 28 days EC
LOG5
LOG6
LOG7

ACT     E03
TITLE   Electrical - 3rd Floor
ES      03/07/90
ESA
EF      03/14/90
EFA
AS        /  /
AF        /  /
TF          0
OD         6
RD        24
LOG1    Change orders #39 41 42 44 45 46 47; 18 days EC
LOG2
LOG3
LOG4
LOG5
LOG6
LOG7

ACT     E04
TITLE   Electrical - 4th Floor
ES      03/15/90
ESA
EF      03/26/90
EFA
AS        /  /
AF        /  /
TF          0
OD         8
RD        52
LOG1    C.O. #52 55 57 62 63 66 67 70 76 77; 43 days EC
LOG2    Delays in electrical installations; 1 day NE
LOG3
LOG4
LOG5
LOG6
LOG7
```

Fig. 6.2. Updated dBASE File for Second Time Period

```
ACT     EL00
TITLE   Elevators - All Floors
ES      10/02/90
ESA
EF      04/18/91
EFA
AS        /  /
AF        /  /
TF          0
OD       135
RD       154
LOG1    Change orders #78, 86, 87; 2 days EC
LOG2    Delays in installing elevators; 17 days NE
LOG3
LOG4
LOG5
LOG6
LOG7

ACT     F02
TITLE   Misc. Finishes - 2nd Floor
ES      09/18/90
ESA
EF      12/17/90
EFA
AS        /  /
AF        /  /
TF         47
OD        65
RD        72
LOG1    Abnormal weather; 7 days EN
LOG2
LOG3
LOG4
LOG5
LOG6
LOG7

ACT     F03
TITLE   Misc. Finishes - 3rd Floor
ES      09/21/90
ESA
EF      12/20/90
EFA
AS        /  /
AF        /  /
TF         47
OD        65
RD        75
LOG1    Design change, delivery of railing; 10 days EC
LOG2
LOG3
LOG4
LOG5
LOG6
LOG7
```

Fig. 6.3. Updated dBASE File for Third Time Period

```
ACT     F04
TITLE   Misc. Finishes - 4th Floor
ES      09/26/90
ESA
EF      01/04/91
EFA
AS        /  /
AF        /  /
TF         47
OD        65
RD        85
LOG1    Design conflicts; 20 days EC
LOG2
LOG3
LOG4
LOG5
LOG6
LOG7

ACT     E16
TITLE   Electrical - Roof
ES      12/04/90
ESA
EF      12/13/90
EFA
AS        /  /
AF        /  /
TF         57
OD          8
RD        38
LOG1    Design change, penthouse suite; 30 days EC
LOG2
LOG3
LOG4
LOG5
LOG6
LOG7
```

Fig. 6.3. Updated dBASE File for Third Time Period (continued)

the dBASE before and after documentation and updating as well as in Primavera for the respective schedules which are duplicated before the export and import functions.

For updating the schedule, considering the delayed activities falling within the first time period, which are activities S00, M01, S01, and S02, their related delays coded in the log records indicate the durations of each type of delay, which accumulate to a total delay to each activity. This delay was added to the original duration of the relevant activity in order to determine the new remaining duration, adjusted into the dBASE. The updated file was imported into Primavera to update the as-planned schedule, the new adjusted schedule referred to as ABS1 (As-Built Snapshot 1) shows a new completion date (20 November 1990), as shown in Fig. 6.4. This new date was compared to the as-planned completion date (7 August 1990), and the 75 working days discrepancy between both schedules were stored in the file for later analyses.

Similarly the delayed activities falling in the second time period, including activities S03, E03, and E04, were updated within the dBASE, and imported to Primavera to update ABS1 schedule, and generate a second adjusted schedule called ABS2 (As-Built Snapshot 2) with a new completion date (18 April 1991), as shown in Fig. 6.5. This schedule includes all delayed activities till the end of the second time period. ABS2 was compared with ABS1, and the difference of both schedules resulted in 99 working days.

Delayed activities falling in the third time period, including activities EL00, F02, F03, F04, and E16 were updated and imported into Primavera in order to update ABS2. The

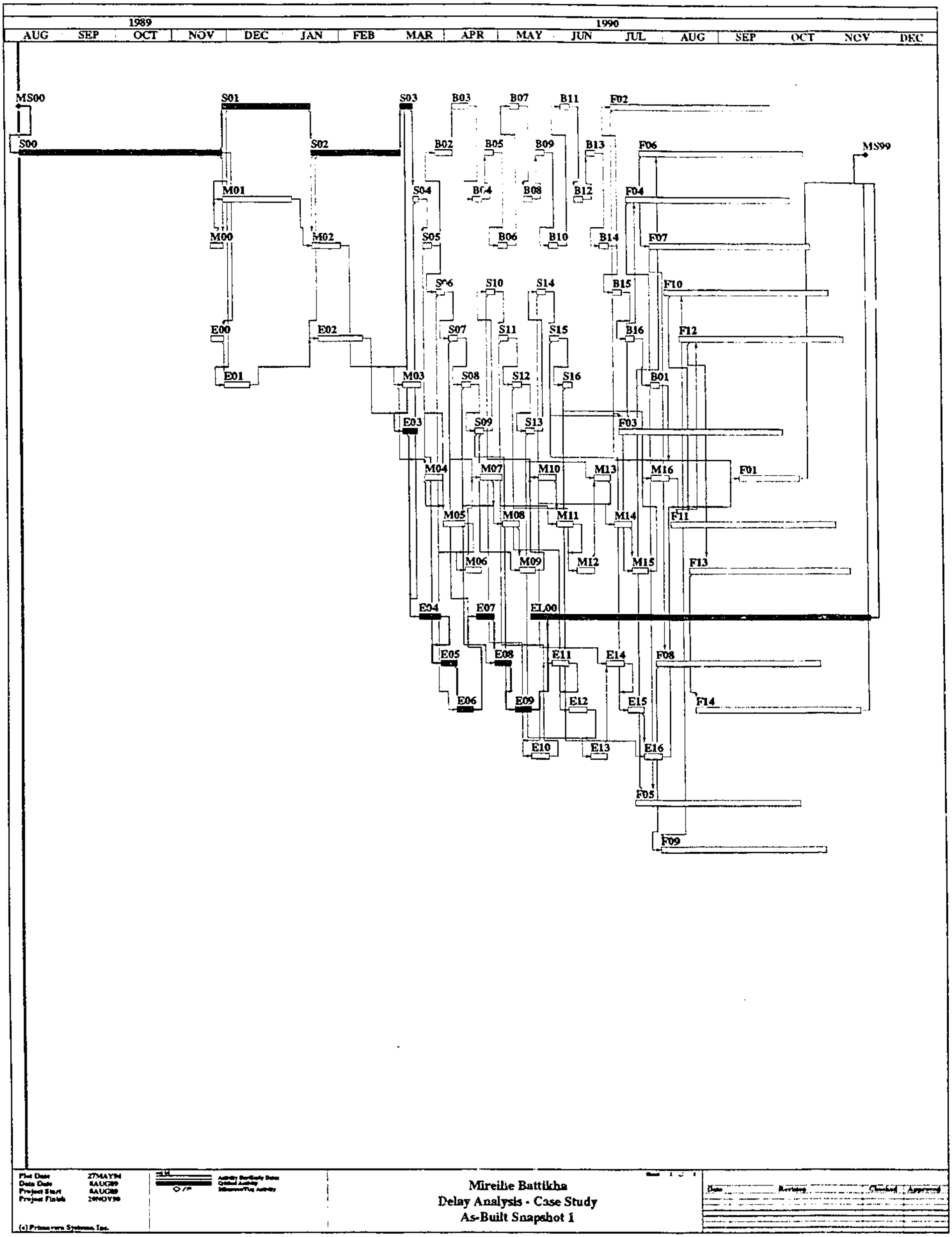

Fig. 6.4. ABS1 Schedule; Case Study

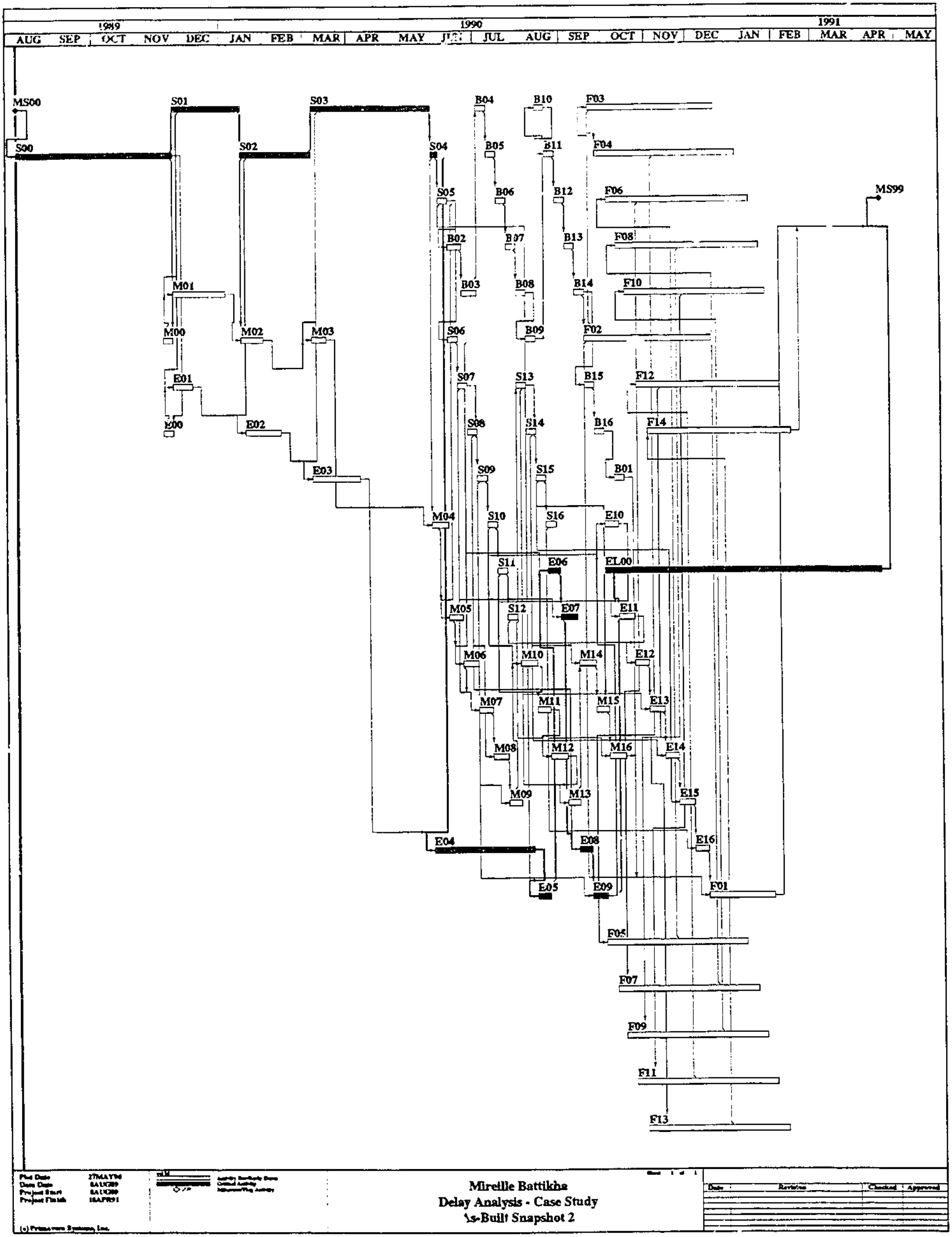

Fig. 6.5. ABS2 Schedule; Case Study

third adjusted schedule ABS3 (As-Built Snapshot 3) revealed a new completion date (15 May 1991) as shown in Fig. 6.6. This schedule was compared with ABS2 and the varia resulted in 19 working days. At this stage, an as-built schedule has been established and includes all the information needed to perform further delay analyses. The as-built schedule referred to in Fig. 6.7, is identical to the last updated schedule ABS3, and reflects a difference of 193 working days (by adding all the delays during the three time periods, 75 + 99 + 19 = 193) when compared to the as-planned completion date. The as-planned and the as-built schedule reports are provided in the appendix, listing activities grouped according to their work areas. In addition, a schedule report comparing the as-built with the as-planned schedules, listing activities in a chronological order, is also provided.

6.4 Delay Analysis; Case Study

Consulting the expert system for this case study was not necessary, since types of delays were already determined. Such delays were coded in the log records during documentation, as EC, EN, or NE. However, the integration process has been validated in previous studies (Alkass et al. 1993). In addition, concurrent delays were not recorded since the schedule had only one critical path. Indeed, the procedure of adjusting concurrent delays, has been successfully conducted in the test case analyzed in chapter three. Therefore, the schedules required for performing the delay analysis described in chapter three were generated for the three time periods as follows:

From the ABS1 schedule, the activities that had in their log records NE delays (contractor's fault) were isolated within Primavera, (using the selection capability), and

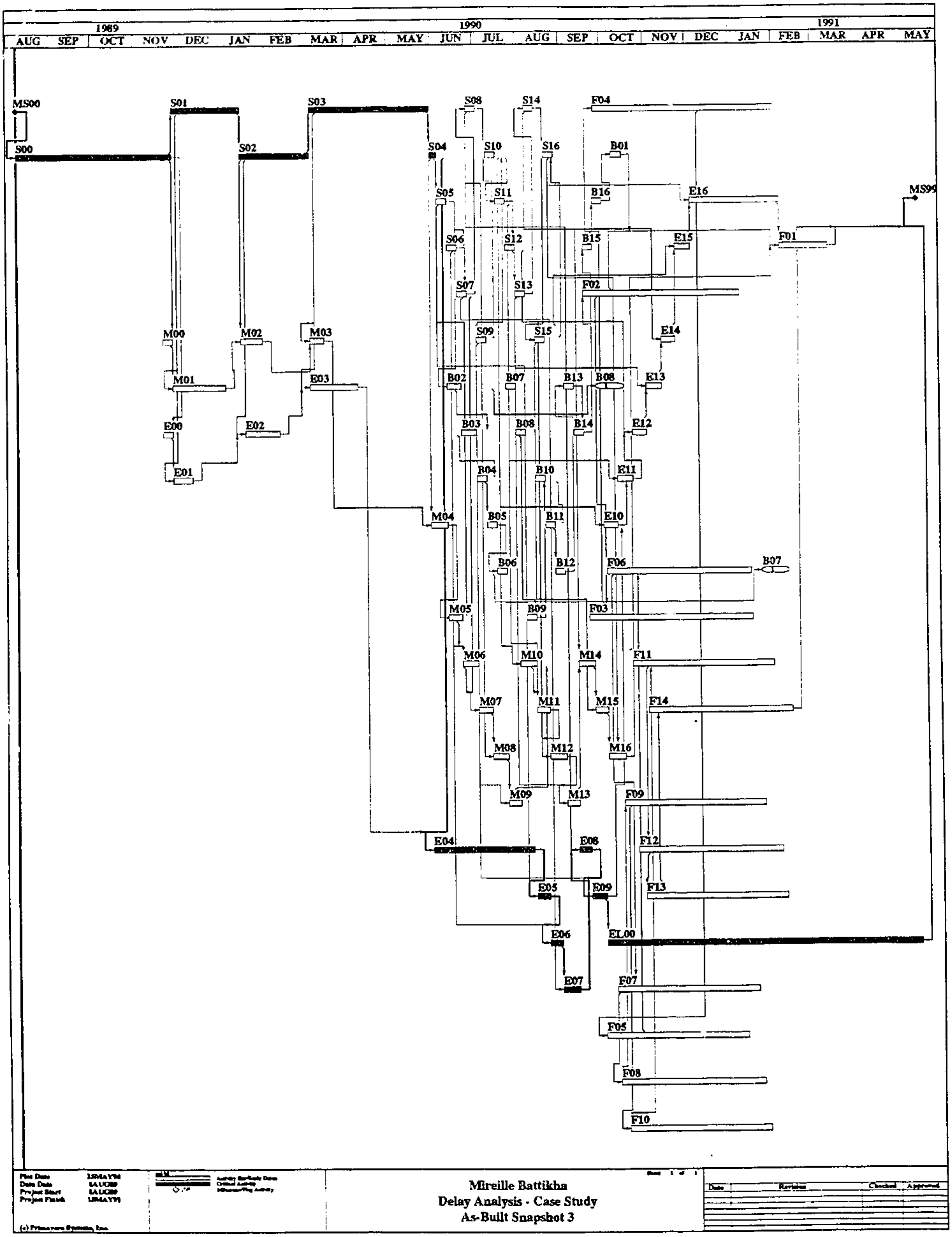

Fig. 6.6. ABS3 Schedule; Case Study

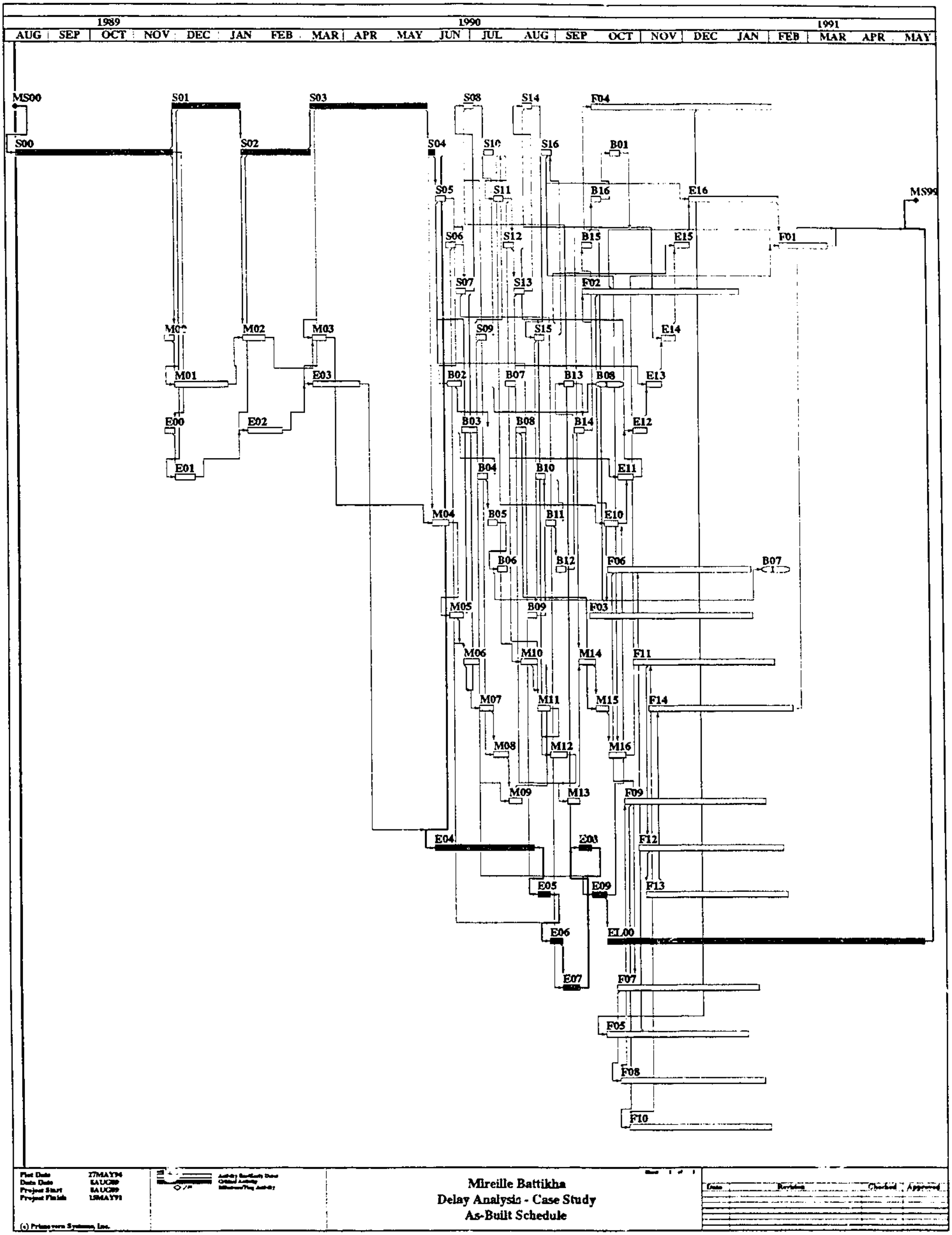

Fig. 6.7. As-Built Schedule; Case Study

exported to dBASE. The remaining duration of these activities were adjusted to exclude the duration of the NE delays, and the file was imported to ABS1 schedule into Primavera, in order to determine a schedule referred to as BCS1 (But For Contractor Snapshot 1), as illustrated in Fig. 6.8. The completion date of BCS1 of 13 November 1990, compared with ABS1 completion date gave 5 days delay due to NE delays.

For the owner's delays, the EN and the EC durations were excluded from the ABS1 delayed activities, and the ABS1 was rescheduled to determine a new schedule called BOS1 (But For Owner Snapshot 1) as shown in Fig. 6.9. Comparing the completion dates of ABS1 and BOS1 resulted in a delay of 71 working days due to the owner.

Using the proportional adjustment to adjust the sum of both parties delays during the first time period, which was 5 + 71 = 76, in order to equate the 75 total delays found previously, the ratio was applied:

76 - 75 = 1 day delay due to neither party

5 - [(71/76) * 1] = 4.06 (4; rounded) days due to the contractor

71 - [(5/76) * 1] = 70.93 (71; rounded) days due to the owner

When calculating the EC and EN delays for the first time period, the BCS1 schedule was used. Excluding the EC delays from BCS1 resulted in a completion date of 24 August 1990, as demonstrated in Fig. 6.10. This schedule was called BES1 (But For Contractor and EC Snapshot 1), and was compared with BCS1. The comparison revealed a delay of 57 working days due to EC. Similarly the EN delays were excluded from BCS1 and the

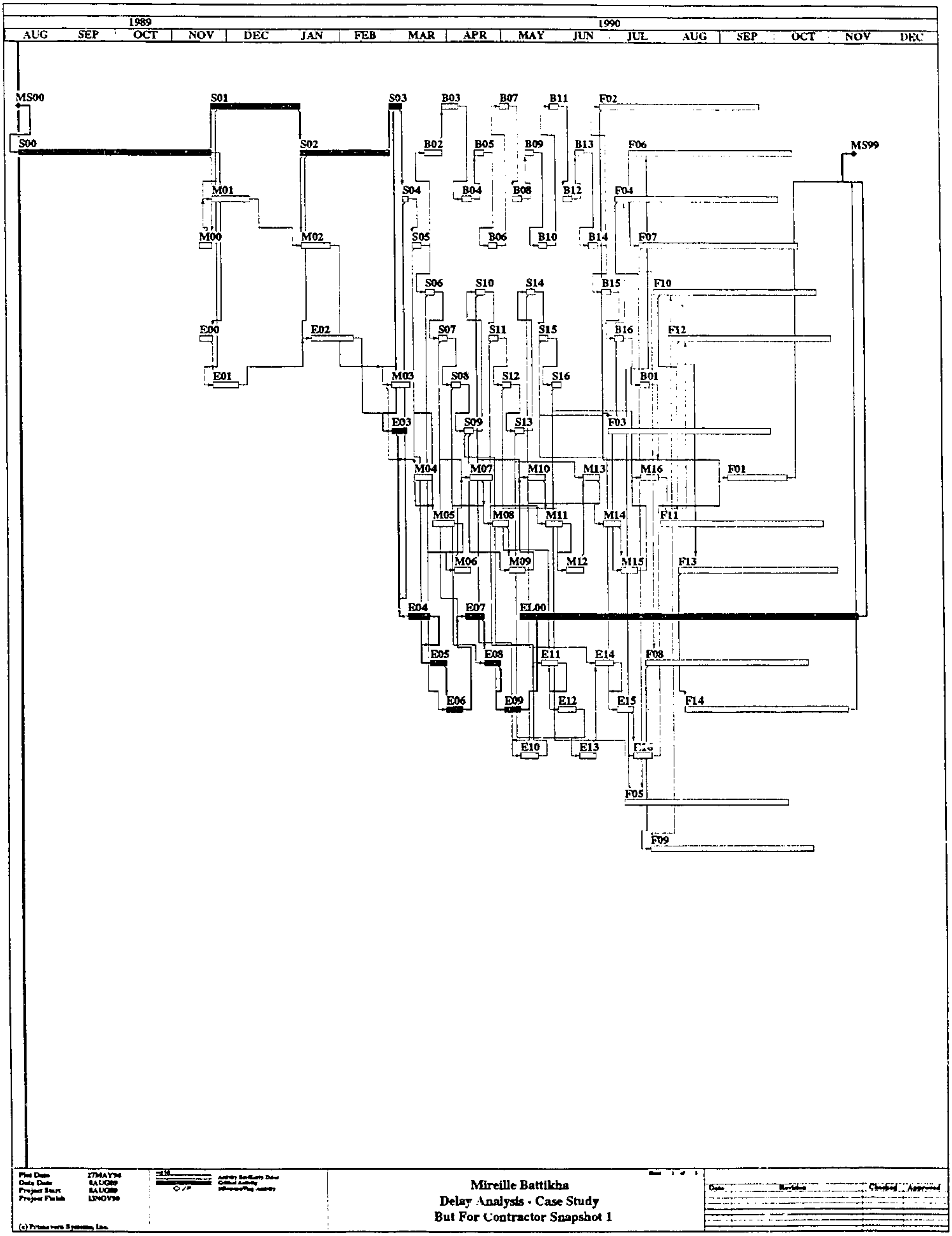

Fig. 6.8. BCS1 Schedule; Case Study

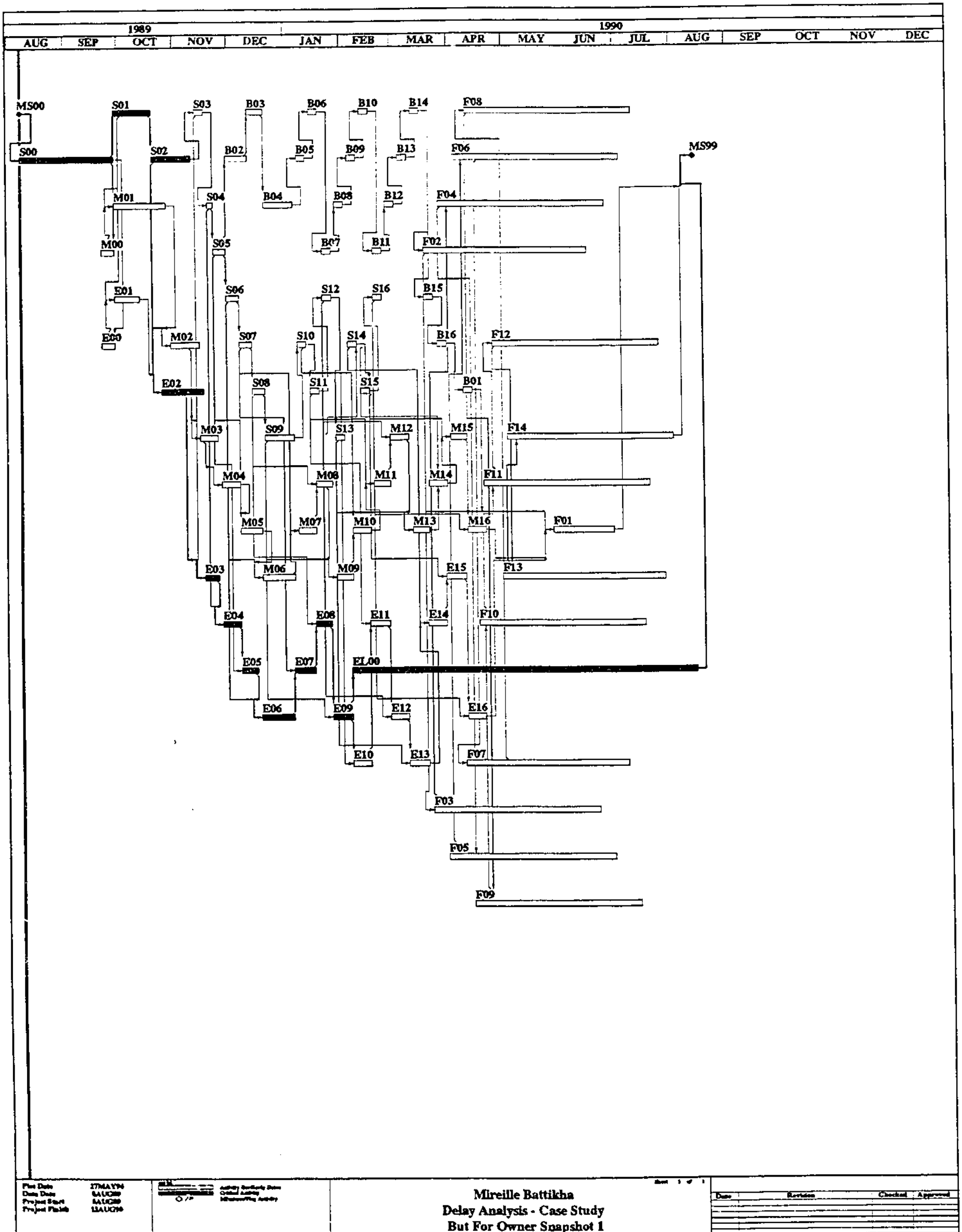

Fig. 6.9. BOS1 Schedule; Case Study

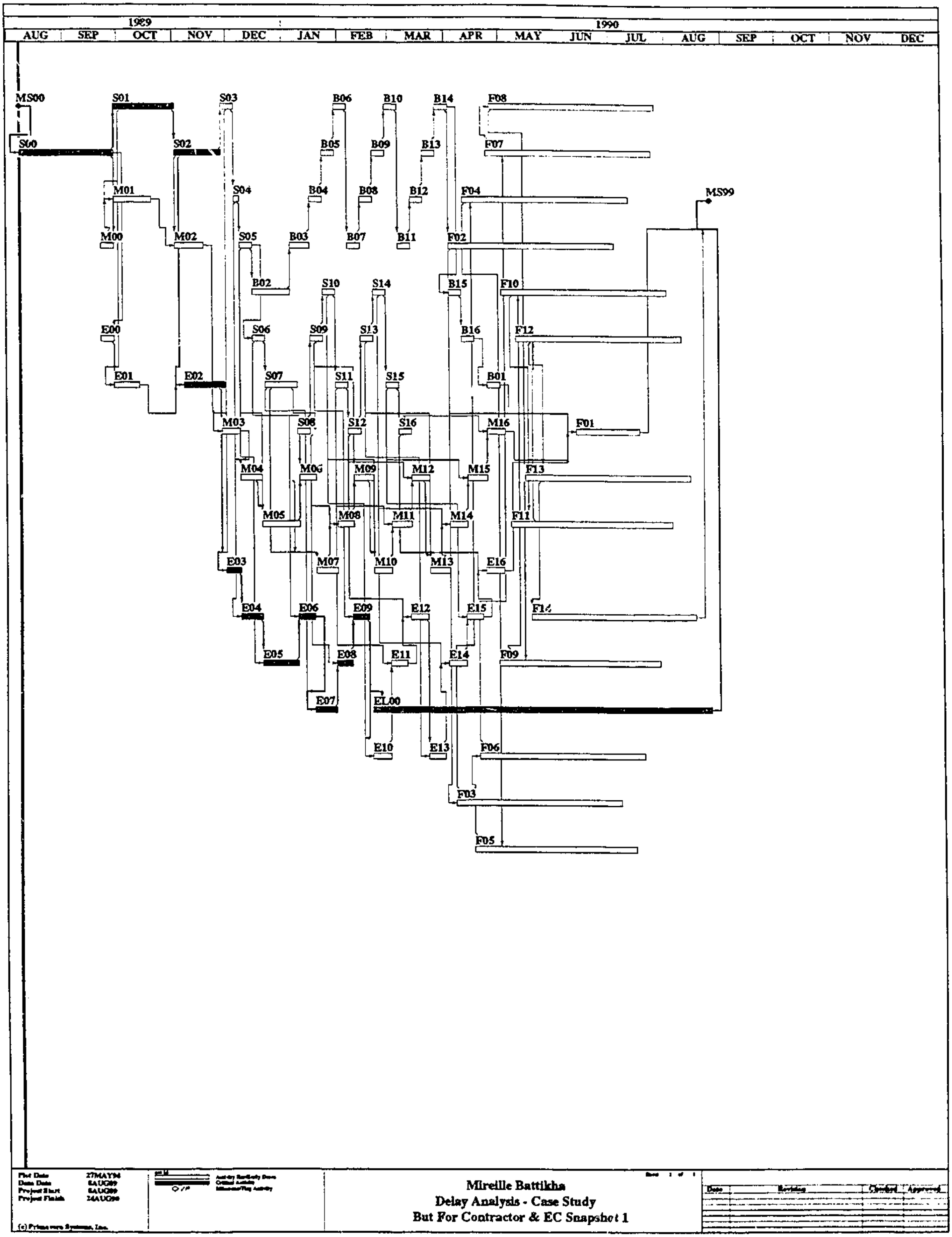

Fig. 6.10. BES1 Schedule; Case Study

new generated schedule, BNS1 (But For Contractor and EN Snapshot 1), was compared with BCS1. The EN delays during that period were found to be 16 working days, since BNS1 completion date was 22 October 1990 as shown in Fig. 6.11.

Adjusting the sum of 57 and 16 days to equate the 71 days due to the owner, found previously, the proportional ratio was used and the result gave 57 days due to EC delays, and 14 days due to EN delays.

The same procedure was repeated for the second and third time periods, and the following schedules were generated with their respective completion dates:

BCS2 (Fig. 6.12); 2 April 1991

BOS2 (Fig. 6.13); 5 December 1990

BES2 (Fig. 6.14); 12 December 1990

BNS2 (Fig. 6.15); 8 March 1991

BCS3 (Fig. 6.16); 22 April 1991

BOS3 (Fig. 6.17); 13 May 1991

BES3 (Fig. 6.18); 18 April 1991

BNS3 (Fig. 6.19); 22 April 1991

Comparing BOS2 and BCS2 with ABS2 resulted in 88 days delay due to owner and 12 days delay due to contractor. With the proportional ratio adjustment, the contractor's delays were decreased to 11 NE delays. Concerning the EC and EN delays, both BES2 and BNS2 were compared with BCS2, and the resulting delays were 71 days due to EC

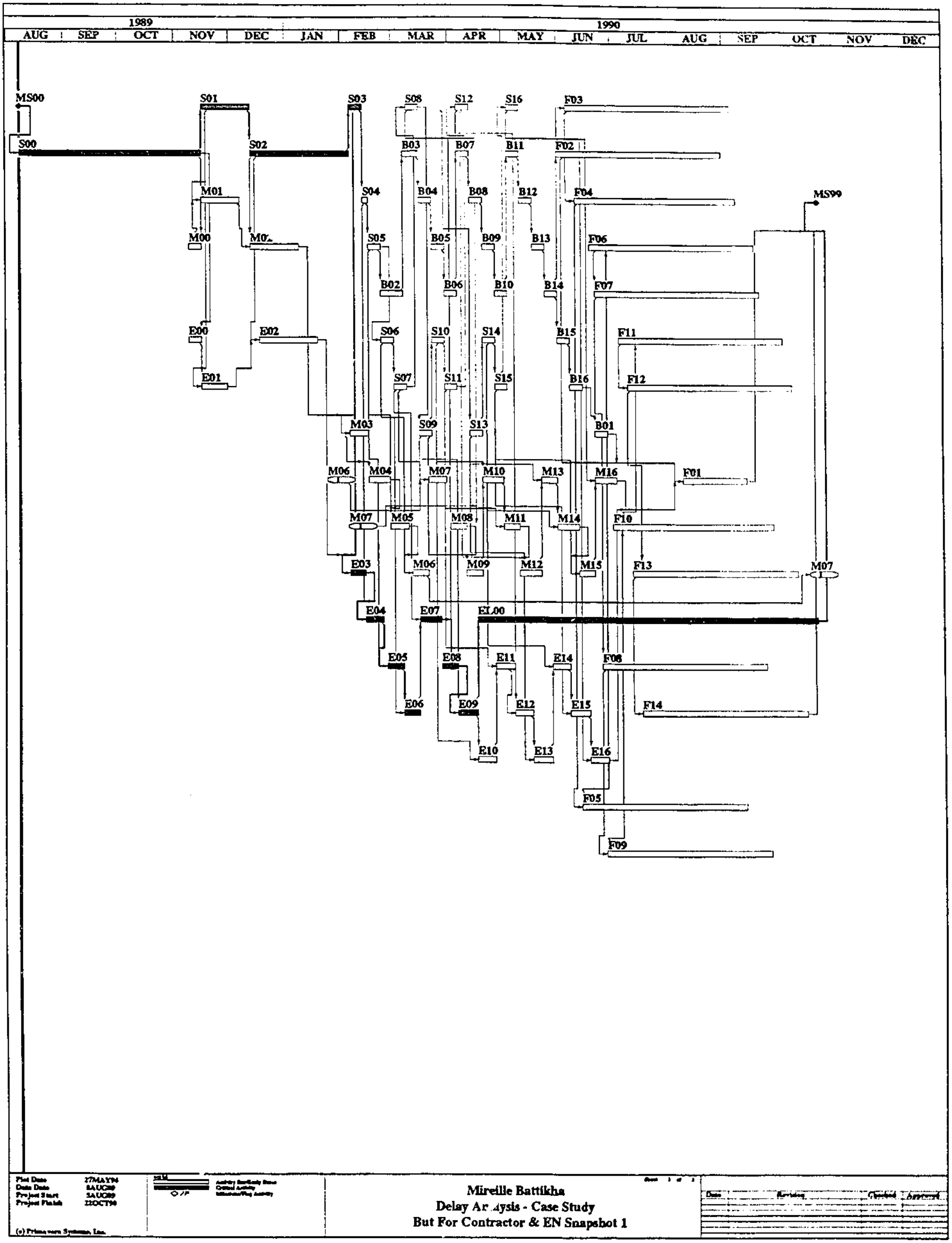

Fig. 6.11. BNS1 Schedule; Case Study

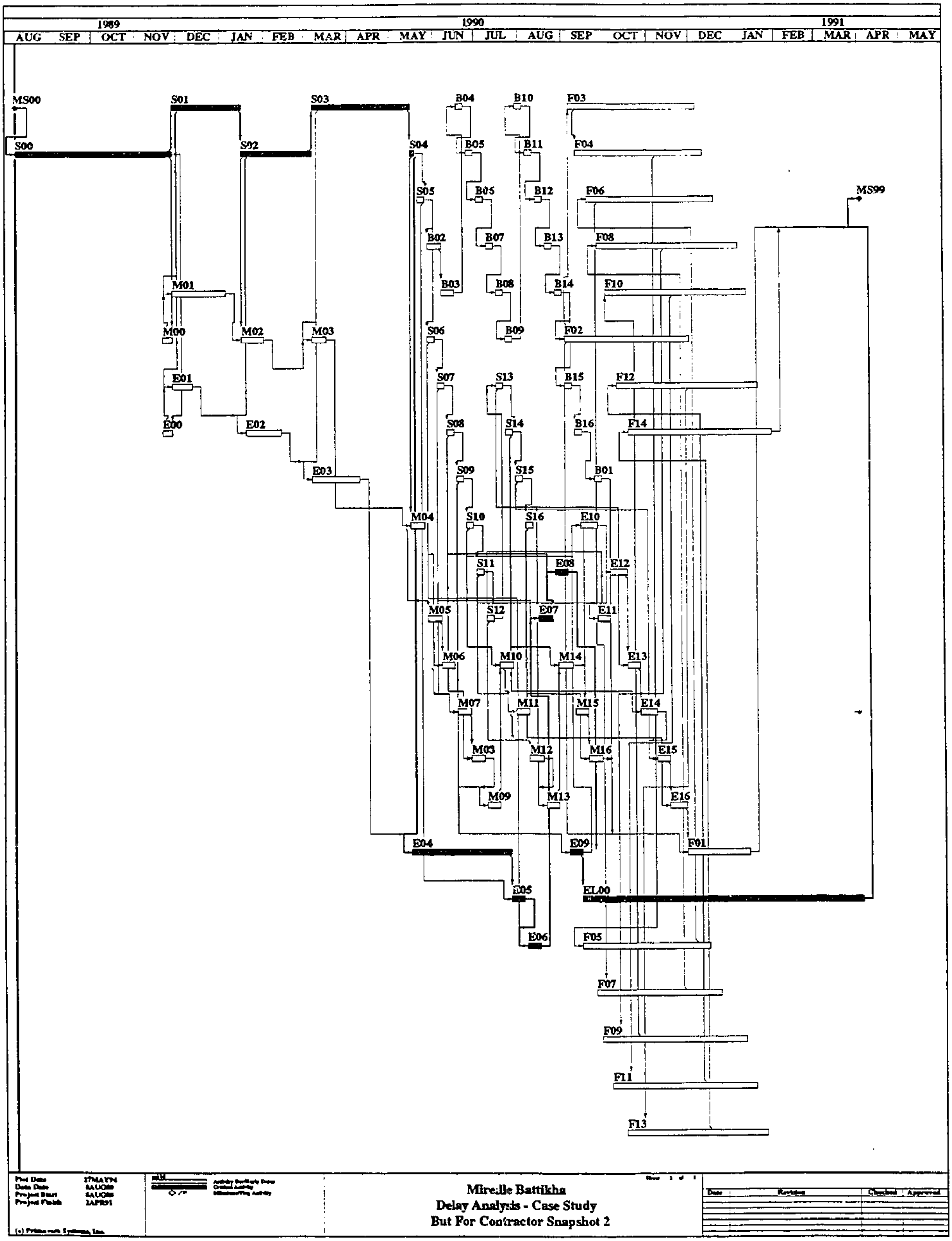

Fig. 6.12. BCS2 Schedule; Case Study

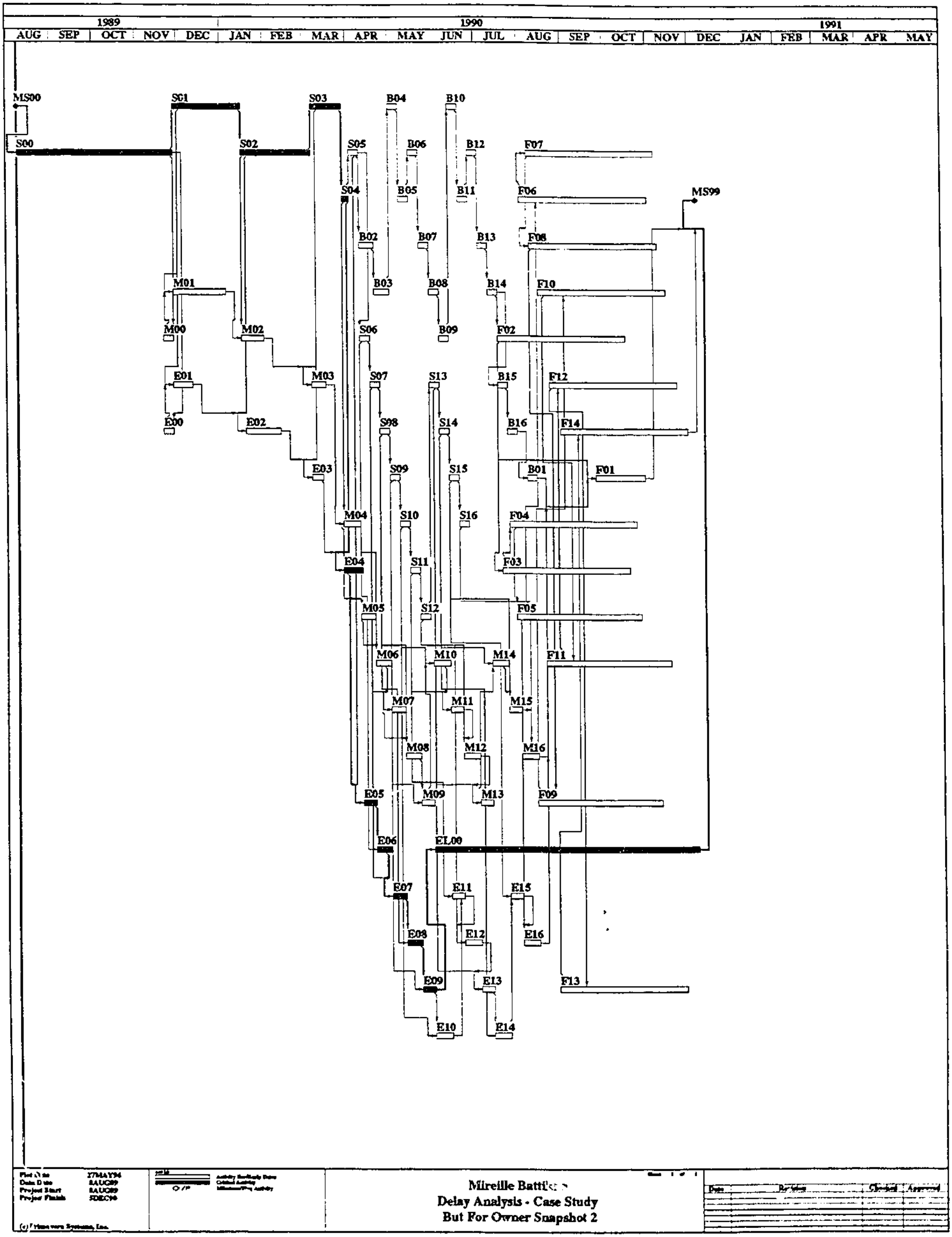

Fig. 6.13. BOS2 Schedule; Case Study

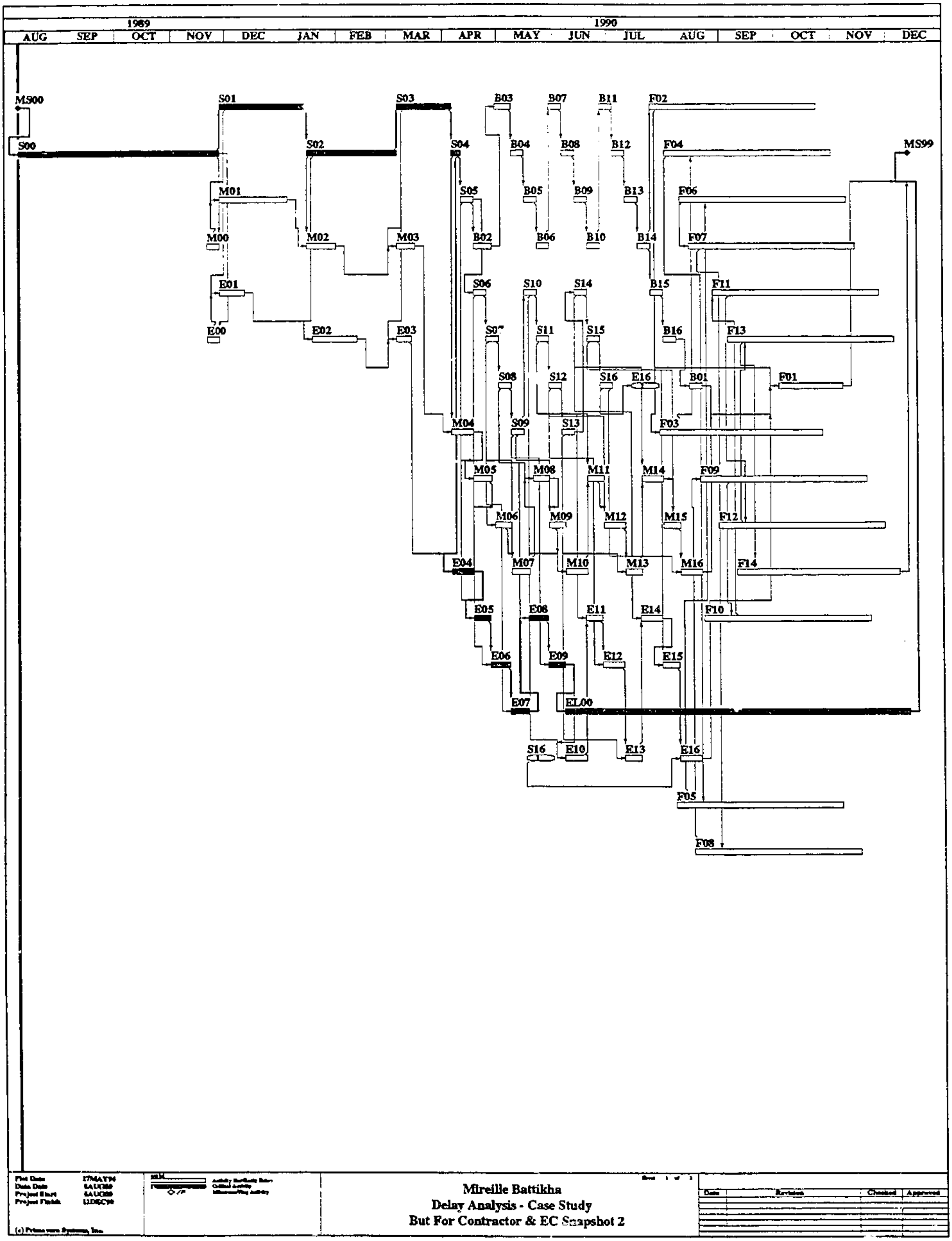

Fig. 6.14. BES2 Schedule; Case Study

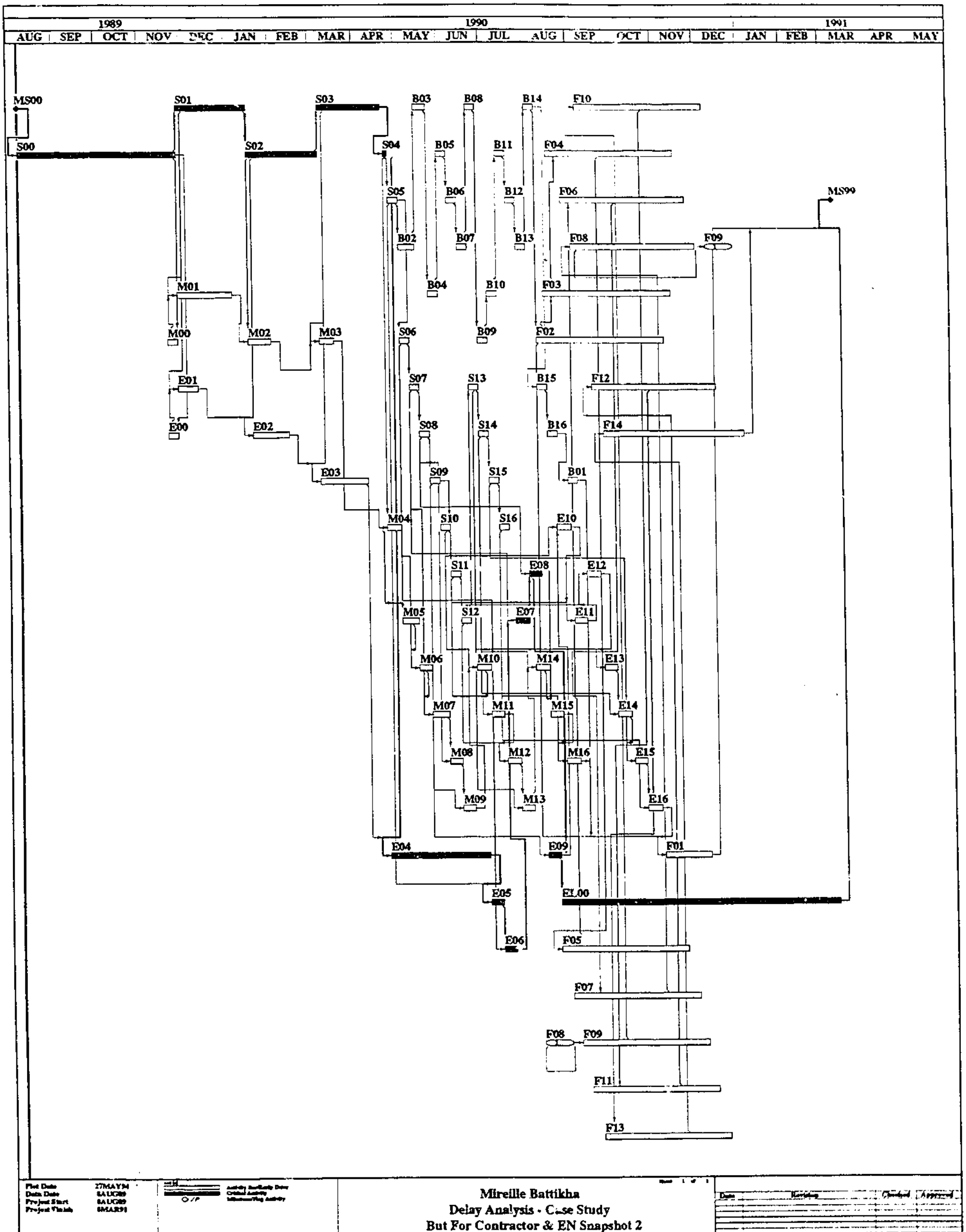

Fig. 6.15. BNS2 Schedule; Case Study

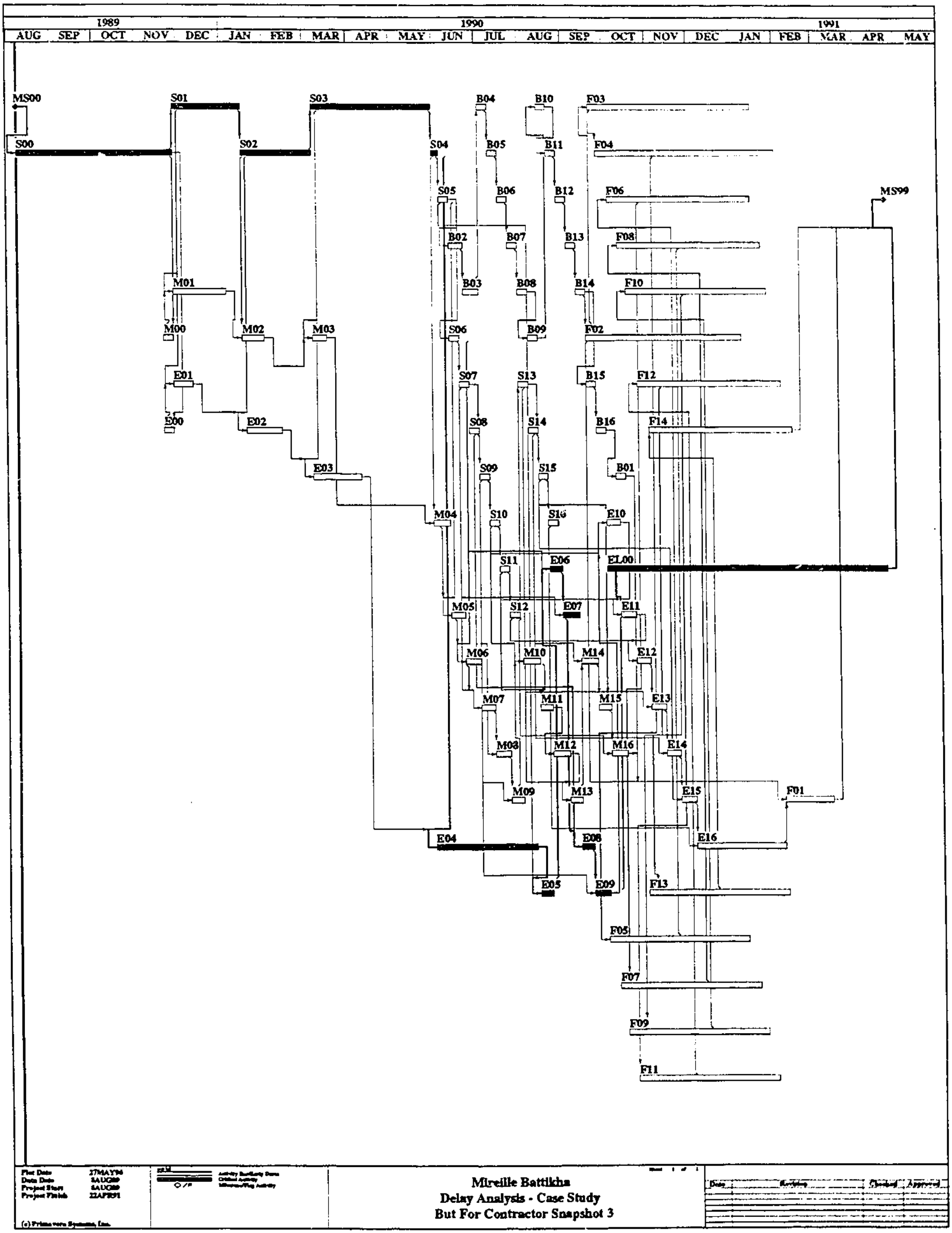

Fig. 6.16. BCS3 Schedule; Case Study

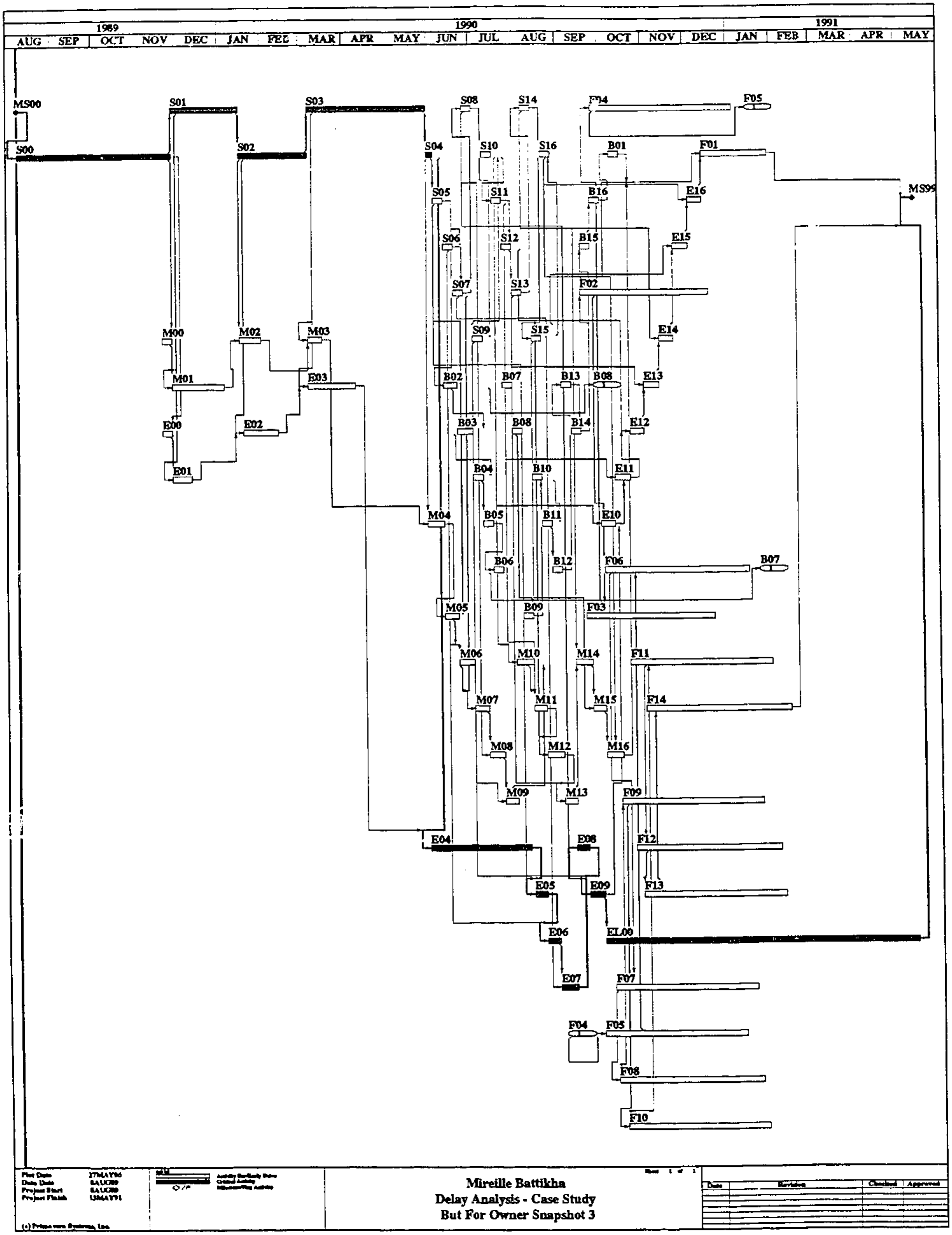

Fig. 6.17. BOS3 Schedule; Case Study

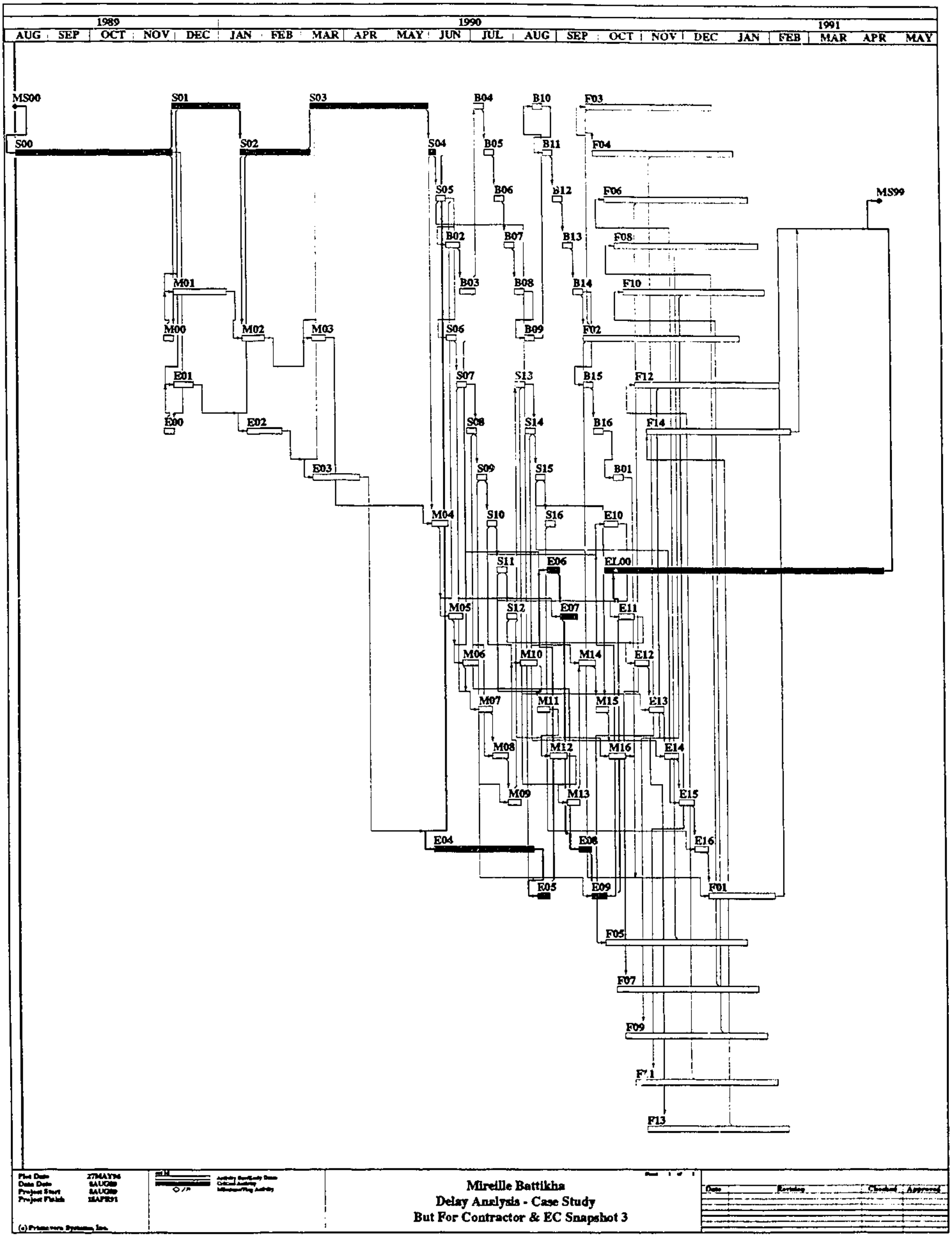

Fig. 6.18. BES3 Schedule; Case Study

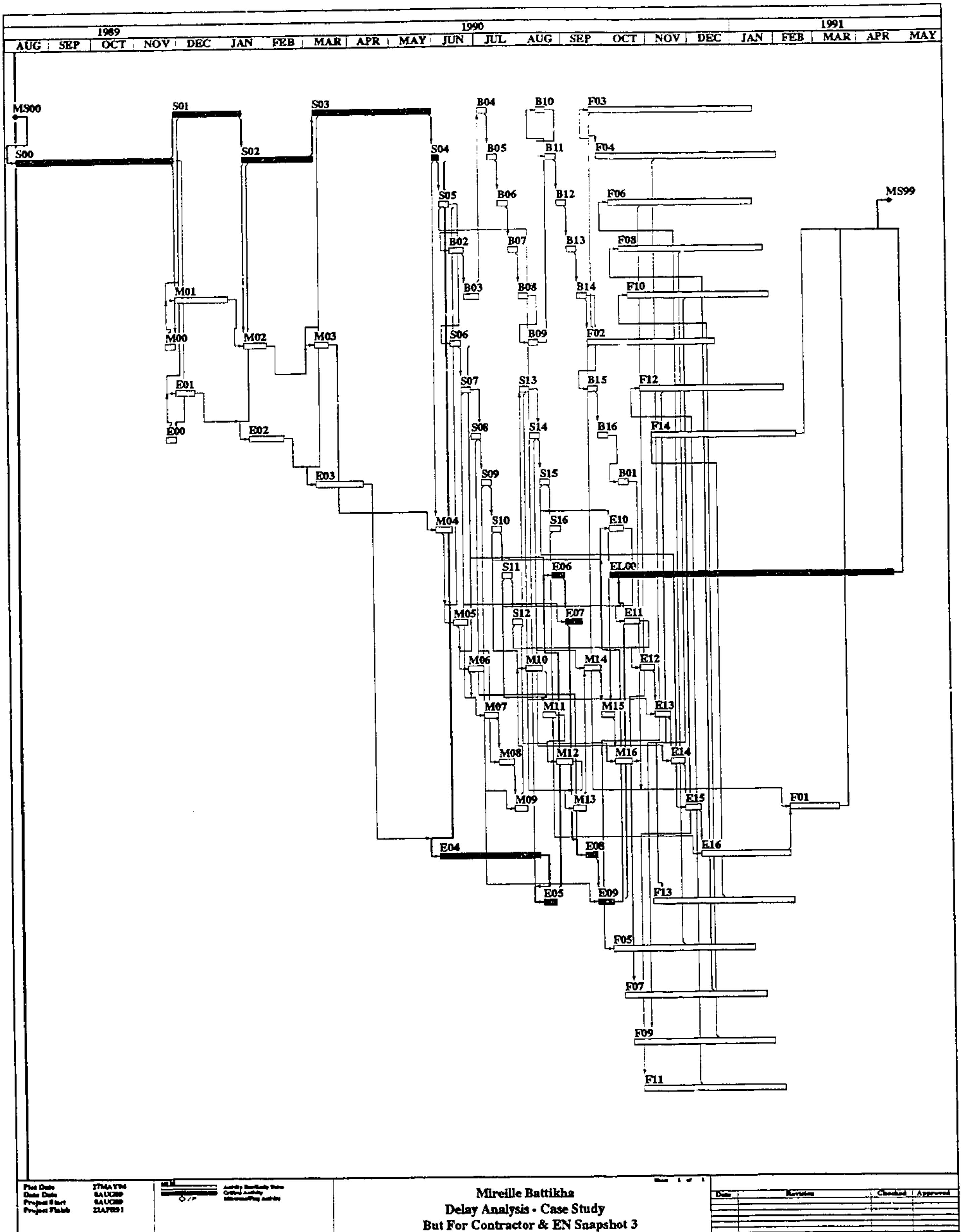

Fig. 6.19. BNS3 Schedule; Case Study

and 17 days due to EN, thus totalling to a delay of 88 days due to owner, as previously found.

Performing the same analysis for the third time period, the contractor's delays resulted in 17 days NE, while the owner's delays were 2 days. Further the EC delays were only 2 days, and there were no EN delays during that period.

Summing the results for the three time periods, the total owner's delays were:

71 + 88 + 2 = 161 days due to owner, including EC and EN delays.

While the contractor's delays (NE), to which the owner is entitled to claim for liquidated damages, were:

4 + 11 + 17 = 32 NE days.

The EC delays, to which the contractor is entitled to claim for time extension and extra costs, were:

57 + 71 + 2 = 130 EC delays.

The EN delays, to which the contractor is entitled to claim for time extension, were:

14 + 17 + 0 = 31 EN days.

Thus the contractor could claim a time extension for 161 days, but could claim extra costs for only 130 days.

6.5 Impact Costs Quantification; Case Study

From the delay analysis the excusable compensable (EC) delays were found to be 130 working days. Their impact costs related to productivity loss was calculated using the equation that was established in chapter four:

[4] $Y = 13.8585 + 0.0986X$

Converting the 130 days delay to a percentage extended duration:

$(130/254) * 100 = 51.18\%$

Replacing X by 51.18, the percentage productivity loss was calculated:

$Y = 13.8585 + (0.0986 * 51.18) = 18.9\%$

These calculation procedures were performed in the Spreadsheet. The percentage loss of productivity was multiplied by the actual manhours of the project (163,108hrs), and then converted to monetary value by multiplying the result by the average labour hour cost ($18.93):

$(0.189) * (163{,}108) * (18.93) = \$583{,}563$

These impact costs were added to the direct, indirect, and overhead costs already stored in the Spreadsheet.

6.6 Findings of System Validation

The delay analysis already performed to the case study using the But For Owner (Collapse) technique, resulted in 165 working days due to the owner's delays. The schedule of this technique is shown in Fig. 6.20, and the completion date of 14 September 1990, was compared against the as-built schedule, with a completion date of 15 May 1991.

Further, the But For technique, was applied for the contractor's delays and the schedule completion date of 28 March 1991, as shown in Fig. 6.21, was compared with the 15 May

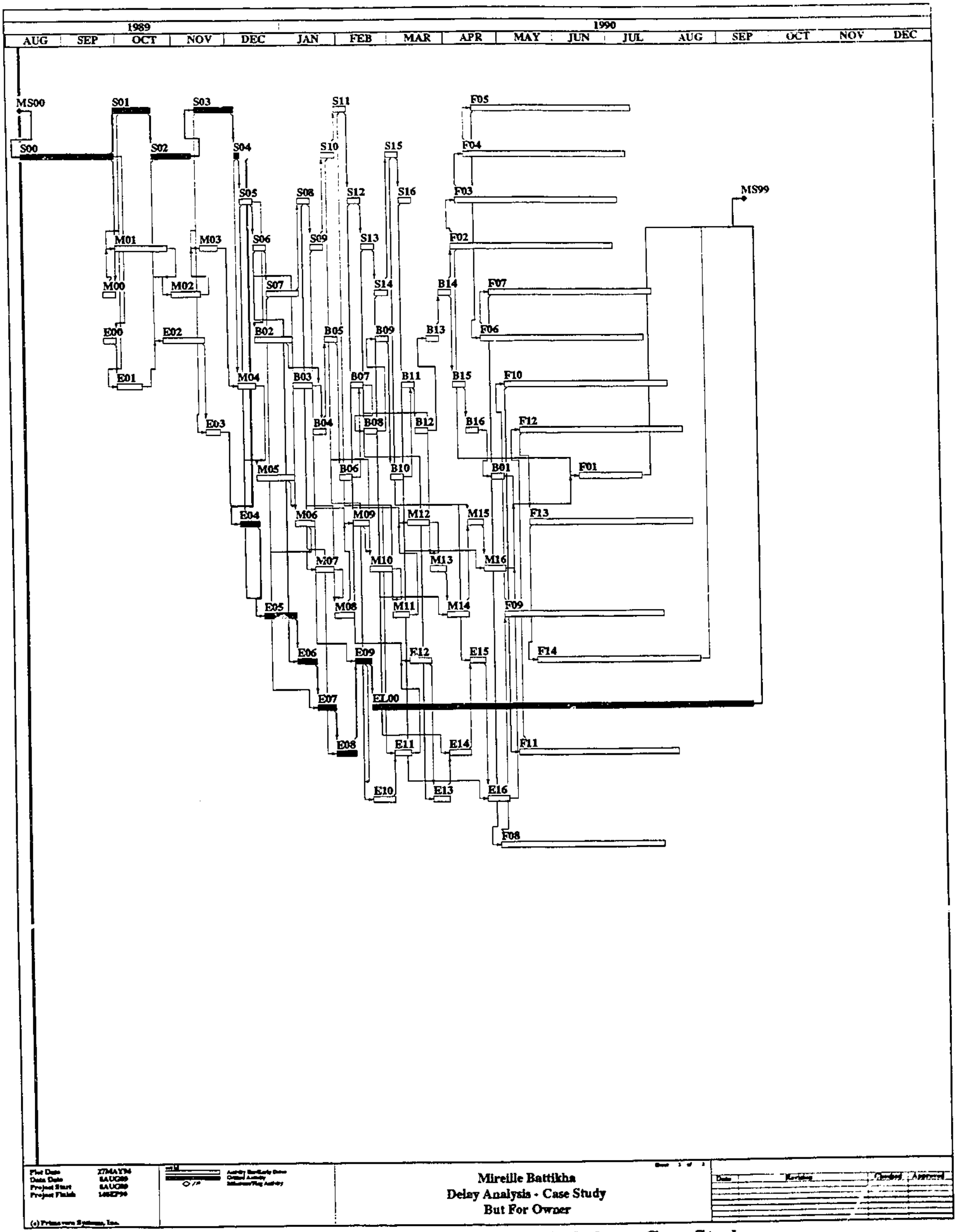

Fig. 6.20. But For Owner's Delays; Case Study

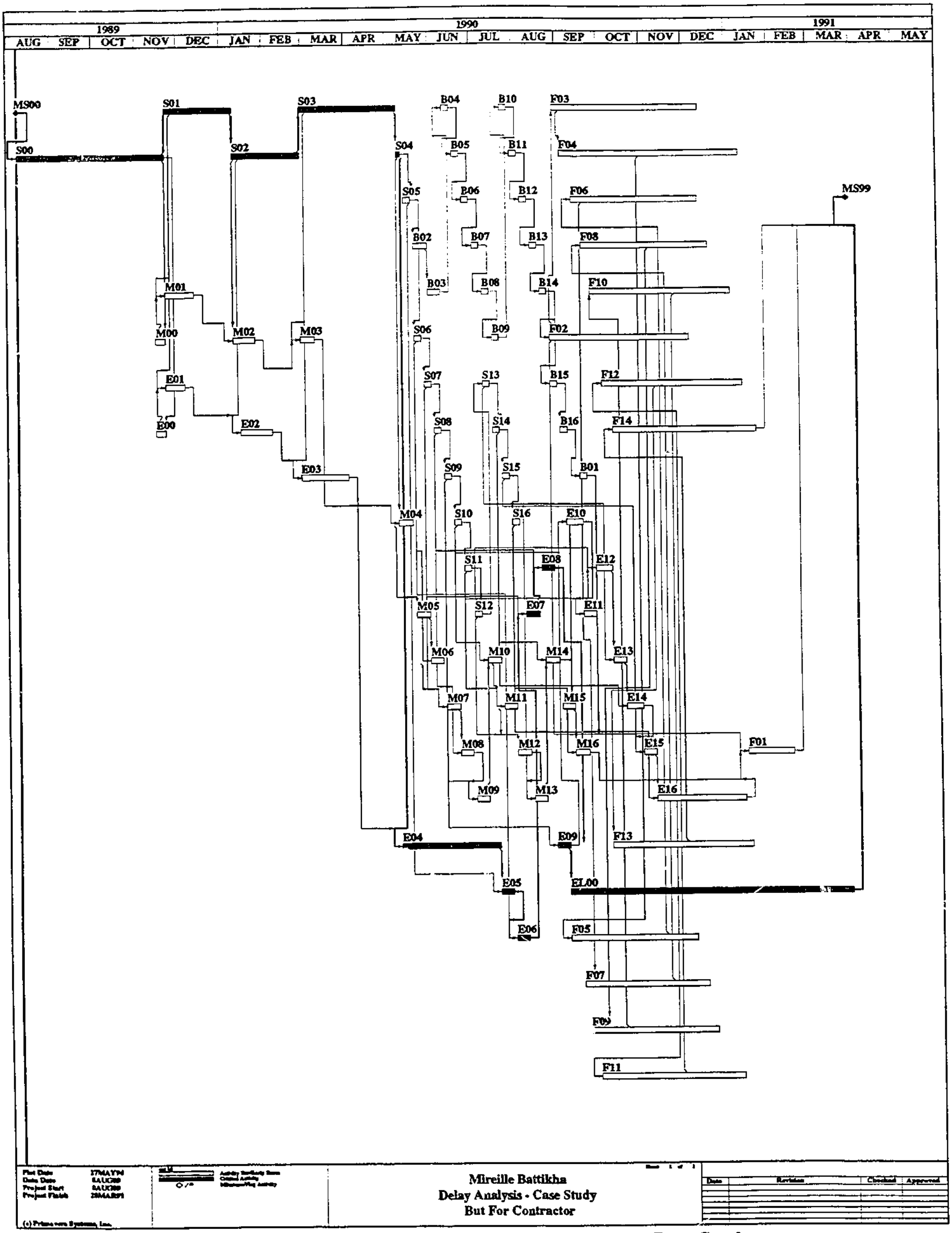

Fig. 6.21. But For Contractor's Delays; Case Study

1991, resulted in 34 days due to the contractor's delays. Thus the total delays for both parties totalled 165 + 34 = 199 days, which is greater than the 193 days total delays found when comparing the as-planned and as-built completion dates. However, the discrepancy of the number of days between the proposed technique and the existing one was minimal, when comparing 165 and 34 against 161 and 32 days respectively.

The proposed integrated system CDAIC, performed reasonably in all its functions including: project track, delay analysis, and impact costs quantification, of the case study.

6.7 Conclusion

A real construction project that has already undergone a delay claim analysis, was selected as a case study to validate the proposed integrated system. An as-planned schedule was used as a start, in conjunction with the information about the delaying events. Those delays were already classified as excusable compensable, excusable noncompensable and nonexcusable. The procedure of the CDAIC system was followed in analyzing the case study, including the project track, delay analysis and impact costs quantification. The results were very close to the documented ones, and the system worked very efficiently, while it has been verified and validated. However the integration process is not fully automated, and the need of the user to check and input information is still necessary. The analysis performed depends greatly on the accuracy of the information that are input in the system, however the system does not replace the judgment of an expert.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The general perception of construction projects is that they are more likely to be completed late, than early or on time. This time overrun beyond the completion date of a project which is defined as a delay, will typically produce financial burdens either due to lost profits, or to increased project costs with resources standing or working at a reduced efficiency. Delays are the most common and costly problem encountered in construction projects, and commonly produce claims by one party to the contract on the other party.

In recent years, considerable attention has been directed towards ascertaining the nature of delays in construction. Attempts are made to find the links between cause and effect damages and entitlements associated with schedule impacts in order to resolve disputes related to delays. Depending on who is seen to be responsible for the delays, the consequences can range from an agreed extension to the project time, to the payment of the contractor's costs, to the deduction of liquidation damages from the contractor's expenses. Thus, preparing a delay claim requires an analysis to determine the entitlements and quantifications. This analysis is usually complex and can be aided by a computerized approach.

The number and magnitude of recent lawsuits as well as the adversarial attitude of the parties in the construction business are indicative of the seriousness of the situation concerning contract disputes. The cost of litigation and the damage to reputations have become so pronounced in the last few years that parties in the construction industry have been trying to minimize disputes and resolve disagreements through fast, economical, convenient, efficient and amicable processes. One such process has been presented in this research.

Currently, several techniques have been utilized by practitioners in the domain of claim analysis to determine the impact of delaying events upon the overall project completion date. However, these techniques have shown a lot of shortcomings in many respects. To overcome these deficiencies, the MIA delay analysis technique was proposed. It determines the amount of time that each party's delays have impacted the project completion date. The technique reflected various advantages, and was tested and validated in a test case and a real case study respectively. It was also presented to practitioners for criticism and input. The new technique provides in addition to the measure of time impact of excusable, and nonexcusable delays, a measure of the time impact of compensable delays as well. This serves as a basis for costs calculations, and especially the impact costs related to the loss of productivity.

Productivity-related impact costs are difficult to quantify, and several methods have been utilized in the industry to determine those costs. However, these methods are not accurate and do not apply to most of the circumstances. A new approach was proposed to quantify the productivity loss due to the extended duration of the project under the impact of compensable delays; since these are the only delays that entitle the contractor to costs compensations, in a delay claim resolution. The results of the analysis demonstrated a confident relationship between the percentage extended duration of the project and the percentage productivity loss. Thus, the additional costs incurred in delays could be estimated, after determining the entitlements utilizing the MIA delay analysis technique.

Both, the MIA delay analysis technique, and the proposed impact costs quantification methodology, were accommodated within the CDAIC (Claims Delay Analysis and Impact Cost calculation) computer integrated system that was proposed for analyzing delays in order to determine the entitlements, and to quantify the impact costs. This approach consisted of integrating existing management software tools, including: project management, database/spreadsheet, and an expert system. The CDAIC, will facilitate the process of claims preparation, thus minimizing both time and cost, which could be mostly valuable in settling construction claims.

System validation and verification were performed using a real case study that had already undergone a claim delay analysis. The validation of CDAIC included: the project track, the delay analysis and the impact costs quantification procedures. The system provides a cost-effective approach for determining entitlements and quantifications, thus improving the management of delay claims resolutions. The CDAIC, could work as a valuable tool in the different methods used for settling disputes such as Alternate Dispute Resolution, Mediation, Arbitration, and Negotiation.

CDAIC could help managers forecast the time extension and the additional costs incurred in delays, beforehand. This could serve in avoiding delays, taking corrective actions, or providing remedies when delays are encountered. The system is designed to employ the software tools that are currently available on construction sites, making it easy and practical to be used by contractors or analysts. In addition, no extra training is required for adopting the system.

There are distinct advantages for developing a computer integrated system that would be able:

1. To perform complex delay schedule analyses in a speedy, accurate, reliable, and economical way using existing computer software;
2. To advise on each party's liabilities in delayed or disrupted activities, using expert system technology;
3. To apportion delayed time between the parties, based on equitable procedures to both the owner and the contractor; and
4. To calculate impact costs related to loss of productivity caused by compensable delays, in a simple and practical manner.

This system could be used to simulate or manage planned delays or disruptions at any given time during the life of a project.

7.2 Recommendations for Further Research

CDAIC will help analysts in preparing claims, however introducing the system to the legal environment, in order to be accepted by courts, legal issues need to be addressed.

This could be done by extending the research to focus on the legal aspect of delays. An expert system would be an ideal tool to embed and display such knowledge and analyses. Though the expert system could provide a lot of advices, the need for an expert might be necessary as well.

Impact costs of delays were quantified, however costs could be further investigated, and costs of other impacts could be studied as well. Other impacts would include: acceleration, poor scheduling, weather effects, etc. Those problems could lead to other claims, which are not related to delays, such as breach of contract, change of materials, poor quality of work, etc. Thus, the proposed system could also be expanded to include claims analyses due to these causes of impacts.

Claims are an integral part of construction projects, thus avoiding them seems to be impossible. However, they could be reduced, if proper claim avoidance measures are taken. For this purpose, the system could be extended and manipulated to serve as a claim avoidance guide.

Presently, the integrated system is not fully automated. Further research is required to fully automate the integration process. This could be the next step to pursue in order to generate a unified computerized process.

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APPENDIX

1. As-Planned Schedule Report; Case Study

2. As-Built Schedule Report with Delays Data; Case Study

3. Schedule Report Comparing As-Built with As-Planned Schedules; Case Study

1. As-Planned Schedule Report; Case Study

ACTIVITY ID	ORIG DUR	REM DUR	%	ACTIVITY DESCRIPTION	EARLY START	EARLY FINISH	TOTAL FLOAT
MS00	0	0	0	Start Project	8AUG89		0
MS99	0	0	0	Finish Project		7AUG90	0
Structure							
S00	34	34	0	Structure - Parking	8AUG89	22SEP89	0
S01	15	15	0	Structure - Ground Floor	25SEP89	13OCT89	0
S02	15	15	0	Structure - 2nd Floor	16OCT89	3NOV89	0
S03	5	5	0	Structure - 3rd Floor	6NOV89	10NOV89	5
S04	3	3	0	Structure - 4th Floor	13NOV89	15NOV89	6
S05	5	5	0	Structure - 5th Floor	16NOV89	22NOV89	9
S06	5	5	0	Structure - 6th Floor	23NOV89	29NOV89	13
S07	5	5	0	Structure - 7th Floor	30NOV89	6DEC89	15
S08	5	5	0	Structure - 8th Floor	7DEC89	13DEC89	18
S09	5	5	0	Structure - 9th Floor	14DEC89	20DEC89	20
S10	5	5	0	Structure - 10th Floor	21DEC89	5JAN90	79
S11	5	5	0	Structure - 11th Floor	8JAN90	12JAN90	82
S12	5	5	0	Structure - 12th Floor	15JAN90	19JAN90	84
S13	5	5	0	Structure - 13th Floor	22JAN90	26JAN90	87
S14	5	5	0	Structure - 14th Floor	29JAN90	2FEB90	89
S15	5	5	0	Structure - 15th Floor	5FEB90	9FEB90	92
S16	5	5	0	Structure - Roof	12FEB90	16FEB90	94
Exterior Brick & Windows							
B01	5	5	0	Ext. Brick & Windows - Ground Floor	2APR90	6APR90	62
B02	8	8	0	Ext. Brick & Windows - 2nd Floor	23NOV89	4DEC89	9
B03	7	7	0	Ext. Brick & Windows - 3rd Floor	5DEC89	13DEC89	9
B04	5	5	0	Ext. Brick & Windows - 4th Floor	14DEC89	20DEC89	9
B05	5	5	0	Ext. Brick & Windows - 5th Floor	21DEC89	5JAN90	9
B06	5	5	0	Ext. Brick & Windows - 6th Floor	8JAN90	12JAN90	9
B07	5	5	0	Ext. Brick & Windows - 7th Floor	15JAN90	19JAN90	9
B08	5	5	0	Ext. Brick & Windows - 8th Floor	22JAN90	26JAN90	9
B09	5	5	0	Ext. Brick & Windows - 9th Floor	29JAN90	2FEB90	9
B10	5	5	0	Ext. Brick & Windows - 10th Floor	5FEB90	9FEB90	9
B11	5	5	0	Ext. Brick & Windows - 11th Floor	12FEB90	16FEB90	9
B12	5	5	0	Ext. Brick & Windows - 12th Floor	19FEB90	23FEB90	9
B13	5	5	0	Ext. Brick & Windows - 13th Floor	26FEB90	2MAR90	9
B14	5	5	0	Ext. Brick & Windows - 14th Floor	5MAR90	9MAR90	9
B15	5	5	0	Ext. Brick & Windows - 15th Floor	12MAR90	16MAR90	62
B16	5	5	0	Ext. Brick & Windows - Roof	19MAR90	23MAR90	62
Mechanical							
M00	5	5	0	Mechanical - Parking	18SEP89	22SEP89	62
M01	15	15	0	Mechanical - Ground Floor	25SEP89	13OCT89	62
M02	12	12	0	Mechanical - 2nd Floor	16OCT89	31OCT89	62
M03	8	8	0	Mechanical - 3rd Floor	6NOV89	15NOV89	59
M04	8	8	0	Mechanical - 4th Floor	16NOV89	27NOV89	59
M05	8	8	0	Mechanical - 5th Floor	28NOV89	7DEC89	59
M06	7	7	0	Mechanical - 6th Floor	8DEC89	18DEC89	59
M07	8	8	0	Mechanical - 7th Floor	19DEC89	8JAN90	59

ACTIVITY ID	ORIG DUR	REM DUR	%	ACTIVITY DESCRIPTION	EARLY START	EARLY FINISH	TOTAL FLOAT
Mechanical							
M08	7	7	0	Mechanical - 8th Floor	9JAN90	17JAN90	59
M09	7	7	0	Mechanical - 9th Floor	18JAN90	26JAN90	59
M10	8	8	0	Mechanical - 10th Floor	29JAN90	7FEB90	59
M11	7	7	0	Mechanical - 11th Floor	8FEB90	16FEB90	59
M12	8	8	0	Mechanical - 12th Floor	19FEB90	28FEB90	59
M13	7	7	0	Mechanical - 13th Floor	1MAR90	9MAR90	59
M14	8	8	0	Mechanical - 14th Floor	12MAR90	21MAR90	59
M15	7	7	0	Mechanical - 15th Floor	22MAR90	30MAR90	59
M16	8	8	0	Mechanical - Roof	2APR90	11APR90	59
Electrical							
E00	5	5	0	Electrical - Parking	18SEP89	22SEP89	8
E01	10	10	0	Electrical - Ground Floor	25SEP89	6OCT89	8
E02	17	17	0	Electrical - 2nd Floor	19OCT89	10NOV89	0
E03	6	6	0	Electrical - 3rd Floor	13NOV89	20NOV89	0
E04	8	8	0	Electrical - 4th Floor	21NOV89	30NOV89	0
E05	7	7	0	Electrical - 5th Floor	1DEC89	11DEC89	0
E06	7	7	0	Electrical - 6th Floor	12DEC89	20DEC89	0
E07	8	8	0	Electrical - 7th Floor	21DEC89	10JAN90	0
E08	7	7	0	Electrical - 8th Floor	11JAN90	19JAN90	0
E09	7	7	0	Electrical - 9th Floor	22JAN90	30JAN90	0
E10	8	8	0	Electrical - 10th Floor	31JAN90	9FEB90	57
E11	7	7	0	Electrical - 11th Floor	12FEB90	20FEB90	57
E12	8	8	0	Electrical - 12th Floor	21FEB90	2MAR90	57
E13	7	7	0	Electrical - 13th Floor	5MAR90	13MAR90	57
E14	8	8	0	Electrical - 14th Floor	14MAR90	23MAR90	57
E15	7	7	0	Electrical - 15th Floor	26MAR90	3APR90	57
E16	8	8	0	Electrical - Roof	4APR90	13APR90	57
Elevator							
EL00	135	135	0	Elevators - All Floors	31JAN90	7AUG90	0
Miscellaneous Finishes							
F01	25	25	0	Misc. Finishes - Ground Floor	21MAY90	22JUN90	32
F02	65	65	0	Misc. Finishes - 2nd Floor	12MAR90	8JUN90	9
F03	65	65	0	Misc. Finishes - 3rd Floor	15MAR90	13JUN90	9
F04	65	65	0	Misc. Finishes - 4th Floor	20MAR90	18JUN90	9
F05	65	65	0	Misc. Finishes - 5th Floor	23MAR90	21JUN90	9
F06	65	65	0	Misc. Finishes - 6th Floor	28MAR90	26JUN90	9
F07	65	65	0	Misc. Finishes - 7th Floor	2APR90	29JUN90	9
F08	65	65	0	Misc. Finishes - 8th Floor	4APR90	3JUL90	9
F09	65	65	0	Misc. Finishes - 9th Floor	6APR90	5JUL90	9
F10	65	65	0	Misc. Finishes - 10th Floor	10APR90	9JUL90	9
F11	65	65	0	Misc. Finishes - 11th Floor	13APR90	12JUL90	9
F12	65	65	0	Misc. Finishes - 12th Floor	18APR90	17JUL90	9
F13	65	65	0	Misc. Finishes - 13th Floor	23APR90	20JUL90	9
F14	65	65	0	Misc. Finishes - 14th Floor	25APR90	25JUL90	9

2. As-Built Schedule Report with Delays Data; Case Study

Mireille Battikha PRIMAVERA PROJECT PLANNER Delay Analysis - Case Study

REPORT DATE 19JUL94 RUN NO. 5 As-Built Schedule START DATE 8AUG89 FIN DATE 15MAY91
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As-Built Schedule Report, with delays data DATA DATE 8AUG89 PAGE NO. 1

ACTIVITY ID	ORIG DUR	REM DUR	%	ACTIVITY DESCRIPTION	EARLY START	EARLY FINISH	TOTAL FLOAT
MS00	0	0	0	Start Project	8AUG89		0
MS99	0	0	0	Finish Project		15MAY91	0
Structure							
S00	34	80	0	Structure - Parking	8AUG89	27NOV89	0
				House not removed until 17Aug89; 8 days EC			
				Bldg. permit not issued until 6Sep89; 21 days EC			
				Downed crane; 3 days NE			
				Repair shear wall; 1 day NE			
				Rain; 4 days EN			
				Added length to form and pour work; 4 days EC			
				Change orders #23, 33; 5 days EC			
S01	15	28	0	Structure - Ground Floor	28NOV89	15JAN90	0
				High wind; 2 days EN			
				Rain; 4 days EN			
				Heavy snow; 3 days EN			
				Added length to form and pour work; 4 days EC			
S02	15	36	0	Structure - 2nd Floor	16JAN90	5MAR90	0
				Downed crane; 1 day NE			
				Heavy snow; 3 days EN			
				Added length to form and pour work; 9 days EC			
				Change orders #36, 37; 8 days EC			
S03	5	61	0	Structure - 3rd Floor	7MAR90	30MAY90	0
				Trucker strike; 14 days EN			
				Rain; 3 days EN			
				Downed crane; 11 days NE			
				Wait for design changes/clarif.; 28 days EC			
S04	3	3	0	Structure - 4th Floor	31MAY90	4JUN90	0
S05	5	5	0	Structure - 5th Floor	5JUN90	11JUN90	49
S06	5	5	0	Structure - 6th Floor	12JUN90	18JUN90	51
S07	5	5	0	Structure - 7th Floor	19JUN90	25JUN90	53
S08	5	5	0	Structure - 8th Floor	26JUN90	2JUL90	56
S09	5	5	0	Structure - 9th Floor	3JUL90	9JUL90	58
S10	5	5	0	Structure - 10th Floor	10JUL90	16JUL90	106
S11	5	5	0	Structure - 11th Floor	17JUL90	23JUL90	109
S12	5	5	0	Structure - 12th Floor	24JUL90	30JUL90	111
S13	5	5	0	Structure - 13th Floor	31JUL90	6AUG90	114
S14	5	5	0	Structure - 14th Floor	7AUG90	13AUG90	116
S15	5	5	0	Structure - 15th Floor	14AUG90	20AUG90	119
S16	5	5	0	Structure - Roof	21AUG90	27AUG90	121
Exterior Brick & Windows							
B01	5	5	0	Ext. Brick & Windows - Ground Floor	9OCT90	15OCT90	119
B02	8	8	0	Ext. Brick & Windows - 2nd Floor	12JUN90	21JUN90	66
B03	7	7	0	Ext. Brick & Windows - 3rd Floor	22JUN90	2JUL90	66
B04	5	5	0	Ext. Brick & Windows - 4th Floor	3JUL90	9JUL90	66
B05	5	5	0	Ext. Brick & Windows - 5th Floor	10JUL90	16JUL90	66
B06	5	5	0	Ext. Brick & Windows - 6th Floor	17JUL90	23JUL90	66

ACTIVITY ID	ORIG DUR	REM DUR	%	ACTIVITY DESCRIPTION	EARLY START	EARLY FINISH	TOTAL FLOAT
Exterior Brick & Windows							
B07	5	5	0	Ext. Brick & Windows - 7th Floor	24JUL90	30JUL90	66
B08	5	5	0	Ext. Brick & Windows - 8th Floor	31JUL90	6AUG90	66
B09	5	5	0	Ext. Brick & Windows - 9th Floor	7AUG90	13AUG90	66
B10	5	5	0	Ext. Brick & Windows - 10th Floor	14AUG90	20AUG90	66
B11	5	5	0	Ext. Brick & Windows - 11th Floor	21AUG90	27AUG90	66
B12	5	5	0	Ext. Brick & Windows - 12th Floor	28AUG90	3SEP90	66
B13	5	5	0	Ext. Brick & Windows - 13th Floor	4SEP90	10SEP90	66
B14	5	5	0	Ext. Brick & Windows - 14th Floor	11SEP90	17SEP90	66
B15	5	5	0	Ext. Brick & Windows - 15th Floor	18SEP90	24SEP90	119
B16	5	5	0	Ext. Brick & Windows - Roof	25SEP90	1OCT90	119
Mechanical							
M00	5	5	0	Mechanical - Parking	21NOV89	27NOV89	203
M01	15	21	0	Mechanical - Ground Floor	28NOV89	4JAN90	203
				Delays in mechanical installations; 6 days NE			
M02	12	12	0	Mechanical - 2nd Floor	16JAN90	31JAN90	196
M03	8	8	0	Mechanical - 3rd Floor	7MAR90	16MAR90	172
M04	8	8	0	Mechanical - 4th Floor	31MAY90	11JUN90	119
M05	8	8	0	Mechanical - 5th Floor	12JUN90	21JUN90	119
M06	7	7	0	Mechanical - 6th Floor	22JUN90	2JUL90	119
M07	8	8	0	Mechanical - 7th Floor	3JUL90	12JUL90	119
M08	7	7	0	Mechanical - 8th Floor	13JUL90	23JUL90	119
M09	7	7	0	Mechanical - 9th Floor	24JUL90	1AUG90	119
M10	8	8	0	Mechanical - 10th Floor	2AUG90	13AUG90	119
M11	7	7	0	Mechanical - 11th Floor	14AUG90	22AUG90	119
M12	8	8	0	Mechanical - 12th Floor	23AUG90	3SEP90	119
M13	7	7	0	Mechanical - 13th Floor	4SEP90	12SEP90	119
M14	8	8	0	Mechanical - 14th Floor	13SEP90	24SEP90	119
M15	7	7	0	Mechanical - 15th Floor	25SEP90	3OCT90	119
M16	8	8	0	Mechanical - Roof	4OCT90	15OCT90	119
Electrical							
E00	5	5	0	Electrical - Parking	21NOV89	27NOV89	74
E01	10	10	0	Electrical - Ground Floor	28NOV89	11DEC89	74
E02	17	17	0	Electrical - 2nd Floor	19JAN90	12FEB90	53
E03	6	24	0	Electrical - 3rd Floor	7MAR90	9APR90	37
				Change orders #39 41 42 44 45 46 47; 18 days EC			
E04	8	52	0	Electrical - 4th Floor	31MAY90	10AUG90	0
				C.O. #52 55 57 62 63 66 67 70 76 77; 43 days EC			
				Delays in electrical installations; 1 day NE			
E05	7	7	0	Electrical - 5th Floor	13AUG90	21AUG90	0
E06	7	7	0	Electrical - 6th Floor	22AUG90	30AUG90	0
E07	8	8	0	Electrical - 7th Floor	31AUG90	11SEP90	0
E08	7	7	0	Electrical - 8th Floor	12SEP90	20SEP90	0
E09	7	7	0	Electrical - 9th Floor	21SEP90	1OCT90	0
E10	8	8	0	Electrical - 10th Floor	2OCT90	11OCT90	46
E11	7	7	0	Electrical - 11th Floor	12OCT90	22OCT90	46
E12	8	8	0	Electrical - 12th Floor	23OCT90	1NOV90	46

ACTIVITY ID	ORIG DUR	REM DUR	%	ACTIVITY DESCRIPTION	EARLY START	EARLY FINISH	TOTAL FLOAT
Electrical							
E13	7	7	0	Electrical - 13th Floor	2NOV90	12NOV90	46
E14	8	8	0	Electrical - 14th Floor	13NOV90	22NOV90	46
E15	7	7	0	Electrical - 15th Floor	23NOV90	3DEC90	46
E16	8	38	0	Electrical - Roof	4DEC90	5FEB91	46
				Design change, penthouse suite; 30 days EC			
Elevator							
EL00	135	154	0	Elevators - All Floors	2OCT90	15MAY91	0
				Change orders #78, 86, 87; 2 days EC			
				Delays in installing elevators; 17 days NE			
Miscellaneous Finishes							
F01	25	25	0	Misc. Finishes - Ground Floor	6FEB91	12MAR91	46
F02	65	72	0	Misc. Finishes - 2nd Floor	18SEP90	7JAN91	66
				Abnormal weather; 7 days EN			
F03	65	75	0	Misc. Finishes - 3rd Floor	21SEP90	15JAN91	66
				Design change, delivery of railing; 10 days EC			
F04	65	65	0	Misc. Finishes - 4th Floor	26SEP90	4JAN91	66
				Design conflicts; 20 days EC			
F05	65	65	0	Misc. Finishes - 5th Floor	1OCT90	9JAN91	66
F06	65	65	0	Misc. Finishes - 6th Floor	4OCT90	14JAN91	66
F07	65	65	0	Misc. Finishes - 7th Floor	9OCT90	17JAN91	66
F08	65	65	0	Misc. Finishes - 8th Floor	11OCT90	21JAN91	66
F09	65	65	0	Misc. Finishes - 9th Floor	15OCT90	23JAN91	66
F10	65	65	0	Misc. Finishes - 10th Floor	17OCT90	25JAN91	66
F11	65	65	0	Misc. Finishes - 11th Floor	22OCT90	30JAN91	66
F12	65	65	0	Misc. Finishes - 12th Floor	25OCT90	4FEB91	66
F13	65	65	0	Misc. Finishes - 13th Floor	30OCT90	7FEB91	66
F14	65	65	0	Misc. Finishes - 14th Floor	2NOV90	12FEB91	66

3. Schedule Report Comparing As-Built with As-Planned Schedules; Case Study

Mireille Battikha | PRIMAVERA PROJECT PLANNER | Delay Analysis - Case Study

REPORT DATE 19JUL94 RUN NO. 11 | As-Built vs. As-Planned | START DATE 8AUG89 FIN DATE 15MAY91

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Schedule Report, As-Built vs. As-Planned | DATA DATE 8AUG89 PAGE NO. 1

ACTIVITY ID	TAR DUR	CUR DUR	%	CODE	ACTIVITY DESCRIPTION	CURRENT START	EARLY FINISH	TARGET START	EARLY FINISH	VAR.
MS00	0	0	0		Start Project	8AUG89		8AUG89		0
S00	34	80	0		1 Structure - Parking	8AUG89	27NOV89	8AUG89	22SEP89	-46
E00	5	5	0		4 Electrical - Parking	21NOV89	27NOV89	18SEP89	22SEP89	-46
M00	5	5	0		3 Mechanical - Parking	21NOV89	27NOV89	18SEP89	22SEP89	-46
E01	10	10	0		4 Electrical - Ground Floor	28NOV89	11DEC89	25SEP89	6OCT89	-46
M01	15	21	0		3 Mechanical - Ground Floor	28NOV89	4JAN90	25SEP89	13OCT89	-52
S01	15	28	0		1 Structure - Ground Floor	28NOV89	15JAN90	25SEP89	13OCT89	-59
M02	12	12	0		3 Mechanical - 2nd Floor	16JAN90	31JAN90	16OCT89	31OCT89	-59
S02	15	36	0		1 Structure - 2nd Floor	16JAN90	6MAR90	16OCT89	3NOV89	-80
E02	17	17	0		4 Electrical - 2nd Floor	19JAN90	12FEB90	19OCT89	10NOV89	-59
E03	6	24	0		4 Electrical - 3rd Floor	7MAR90	9APR90	13NOV89	20NOV89	-93
M03	8	8	0		3 Mechanical - 3rd Floor	7MAR90	16MAR90	6NOV89	15NOV89	-80
S03	5	61	0		1 Structure - 3rd Floor	7MAR90	30MAY90	6NOV89	10NOV89	-136
E04	8	52	0		4 Electrical - 4th Floor	31MAY90	10AUG90	21NOV89	30NOV89	-174
M04	8	8	0		3 Mechanical - 4th Floor	31MAY90	11JUN90	16NOV89	27NOV89	-133
S04	3	3	0		1 Structure - 4th Floor	31MAY90	4JUN90	13NOV89	15NOV89	-136
S05	5	5	0		1 Structure - 5th Floor	5JUN90	11JUN90	16NOV89	22NOV89	-136
B02	8	8	0		2 Ext. Brick & Windows - 2nd Floor	12JUN90	21JUN90	23NOV89	4DEC89	-136
M05	8	8	0		3 Mechanical - 5th Floor	12JUN90	21JUN90	28NOV89	7DEC89	-133
S06	5	5	0		1 Structure - 6th Floor	12JUN90	18JUN90	23NOV89	29NOV89	-136
S07	5	5	0		1 Structure - 7th Floor	19JUN90	25JUN90	30NOV89	6DEC89	-136
B03	7	7	0		2 Ext. Brick & Windows - 3rd Floor	22JUN90	2JUL90	5DEC89	13DEC89	-136
M06	7	7	0		3 Mechanical - 6th Floor	22JUN90	2JUL90	8DEC89	18DEC89	-133
S08	5	5	0		1 Structure - 8th Floor	26JUN90	2JUL90	7DEC89	13DEC89	-136
B04	5	5	0		2 Ext. Brick & Windows - 4th Floor	3JUL90	9JUL90	14DEC89	20DEC89	-136
M07	8	8	0		3 Mechanical - 7th Floor	3JUL90	12JUL90	19DEC89	8JAN90	-133
S09	5	5	0		1 Structure - 9th Floor	3JUL90	9JUL90	14DEC89	20DEC89	-136
B05	5	5	0		2 Ext. Brick & Windows - 5th Floor	10JUL90	16JUL90	21DEC89	5JAN90	-136
S10	5	5	0		1 Structure - 10th Floor	10JUL90	16JUL90	21DEC89	5JAN90	-136
M08	7	7	0		3 Mechanical - 8th Floor	13JUL90	23JUL90	9JAN90	17JAN90	-133
B06	5	5	0		2 Ext. Brick & Windows - 6th Floor	17JUL90	23JUL90	8JAN90	12JAN90	-136
S11	5	5	0		1 Structure - 11th Floor	17JUL90	23JUL90	8JAN90	12JAN90	-136
B07	5	5	0		2 Ext. Brick & Windows - 7th Floor	24JUL90	30JUL90	15JAN90	19JAN90	-136
M09	7	7	0		3 Mechanical - 9th Floor	24JUL90	1AUG90	18JAN90	26JAN90	-133
S12	5	5	0		1 Structure - 12th Floor	24JUL90	30JUL90	15JAN90	19JAN90	-136
B08	5	5	0		2 Ext. Brick & Windows - 8th Floor	31JUL90	6AUG90	22JAN90	26JAN90	-136
S13	5	5	0		1 Structure - 13th Floor	31JUL90	6AUG90	22JAN90	26JAN90	-136
M10	8	8	0		3 Mechanical - 10th Floor	2AUG90	13AUG90	29JAN90	7FEB90	-133
B09	5	5	0		2 Ext. Brick & Windows - 9th Floor	7AUG90	13AUG90	29JAN90	2FEB90	-136
S14	5	5	0		1 Structure - 14th Floor	7AUG90	13AUG90	29JAN90	2FEB90	-136
E05	7	7	0		4 Electrical - 5th Floor	13AUG90	21AUG90	1DEC89	11DEC89	-174
B10	5	5	0		2 Ext. Brick & Windows - 10th Floor	14AUG90	20AUG90	5FEB90	9FEB90	-136
M11	7	7	0		3 Mechanical - 11th Floor	14AUG90	22AUG90	8FEB90	16FEB90	-133
S15	5	5	0		1 Structure - 15th Floor	14AUG90	20AUG90	5FEB90	9FEB90	-136
B11	5	5	0		2 Ext. Brick & Windows - 11th Floor	21AUG90	27AUG90	12FEB90	16FEB90	-136
S16	5	5	0		1 Structure - Roof	21AUG90	27AUG90	12FEB90	16FEB90	-136
E06	7	7	0		4 Electrical - 6th Floor	22AUG90	30AUG90	12DEC89	20DEC89	-174

ACTIVITY ID	TAR DUR	CUR DUR	%	CODE	ACTIVITY DESCRIPTION	CURRENT START	EARLY FINISH	TARGET START	EARLY FINISH	VAR.
M12	8	8	0		3 Mechanical - 12th Floor	23AUG90	3SEP90	19FEB90	28FEB90	-133
B12	5	5	0		2 Ext. Brick & Windows - 12th Floor	28AUG90	3SEP90	19FEB90	23FEB90	-136
E07	8	8	0		4 Electrical - 7th Floor	31AUG90	11SEP90	21DEC89	10JAN90	-174
B13	5	5	0		2 Ext. Brick & Windows - 13th Floor	4SEP90	10SEP90	26FEB90	2MAR90	-136
M13	7	7	0		3 Mechanical - 13th Floor	4SEP90	12SEP90	1MAR90	9MAR90	-133
B14	5	5	0		2 Ext. Brick & Windows - 14th Floor	11SEP90	17SEP90	5MAR90	9MAR90	-136
E08	7	7	0		4 Electrical - 8th Floor	12SEP90	20SEP90	11JAN90	19JAN90	-174
M14	8	8	0		3 Mechanical - 14th Floor	13SEP90	24SEP90	12MAR90	21MAR90	-133
B15	5	5	0		2 Ext. Brick & Windows - 15th Floor	18SEP90	24SEP90	12MAR90	16MAR90	-136
F02	65	72	0		6 Misc. Finishes - 2nd Floor	18SEP90	7JAN91	12MAR90	8JUN90	-143
E09	7	7	0		4 Electrical - 9th Floor	21SEP90	1OCT90	22JAN90	30JAN90	-174
F03	65	75	0		6 Misc. Finishes - 3rd Floor	21SEP90	15JAN91	15MAR90	13JUN90	-146
B16	5	5	0		2 Ext. Brick & Windows - Roof	25SEP90	1OCT90	19MAR90	23MAR90	-136
M15	7	7	0		3 Mechanical - 15th Floor	25SEP90	3OCT90	22MAR90	30MAR90	-133
F04	65	85	0		6 Misc. Finishes - 4th Floor	26SEP90	1FEB91	20MAR90	18JUN90	-156
F05	65	65	0		6 Misc. Finishes - 5th Floor	1OCT90	9JAN91	23MAR90	21JUN90	-136
E10	8	8	0		4 Electrical - 10th Floor	2OCT90	11OCT90	31JAN90	9FEB90	-174
EL00	135	154	0		5 Elevators - All Floors	2OCT90	15MAY91	31JAN90	7AUG90	-193
F06	65	65	0		6 Misc. Finishes - 6th Floor	4OCT90	14JAN91	28MAR90	26JUN90	-136
M16	8	8	0		3 Mechanical - Roof	4OCT90	15OCT90	2APR90	11APR90	-133
B01	5	5	0		2 Ext. Brick & Windows - Ground Floor	9OCT90	15OCT90	2APR90	6APR90	-136
F07	65	65	0		6 Misc. Finishes - 7th Floor	9OCT90	17JAN91	2APR90	29JUN90	-136
F08	65	65	0		6 Misc. Finishes - 8th Floor	11OCT90	21JAN91	4APR90	3JUL90	-136
E11	7	7	0		4 Electrical - 11th Floor	12OCT90	22OCT90	12FEB90	20FEB90	-174
F09	65	65	0		6 Misc. Finishes - 9th Floor	15OCT90	23JAN91	6APR90	5JUL90	-136
F10	65	65	0		6 Misc. Finishes - 10th Floor	17OCT90	25JAN91	10APR90	9JUL90	-136
F11	65	65	0		6 Misc. Finishes - 11th Floor	22OCT90	30JAN91	13APR90	12JUL90	-136
E12	8	8	0		4 Electrical - 12th Floor	23OCT90	1NOV90	21FEB90	2MAR90	-174
F12	65	65	0		6 Misc. Finishes - 12th Floor	25OCT90	4FEB91	18APR90	17JUL90	-136
F13	65	65	0		6 Misc. Finishes - 13th Floor	30OCT90	7FEB91	23APR90	20JUL90	-136
E13	7	7	0		4 Electrical - 13th Floor	2NOV90	12NOV90	5MAR90	13MAR90	-174
F14	65	65	0		6 Misc. Finishes - 14th Floor	2NOV90	12FEB91	26APR90	25JUL90	-136
E14	8	8	0		4 Electrical - 14th Floor	13NOV90	22NOV90	14MAR90	23MAR90	-174
E15	7	7	0		4 Electrical - 15th Floor	23NOV90	3DEC90	26MAR90	3APR90	-174
E16	8	38	0		4 Electrical - Roof	4DEC90	5FEB91	4APR90	13APR90	-204
F01	25	25	0		6 Misc. Finishes - Ground Floor	6FEB91	12MAR91	21MAY90	22JUN90	-179
MS99	0	0	0		Finish Project		15MAY91		7AUG90	-193