A COMBINATION OF CYCLONE AND VERT TECHNIQUES FOR THE MANAGEMENT OF CONSTRUCTION PROJECTS

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SUMMARY

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Many planning and control tools, especially network analysis, have been developed in the last four decades. The majority of them were created in military organization to solve the problem of planning and controlling research and development projects.
The original version of the network model (i.e. C.P.M/PERT) was transplanted to the construction industry without the consideration of the special nature and environment of construction projects. It suited the purpose of setting up targets and defining objectives, but it failed in satisfying the requirement of detailed planning and control at the site level.

Several analytical and heuristic rules based methods were designed and combined with the structure of C.P.M to eliminate its deficiences, none of them provides a complete solution to the problem of resource , time and cost control.

VERT was designed to deal with new ventures. It is suitable for project evaluation at the development stage. CYCLONE, on the other hand, is concerned with the design and micro-analysis of the production process.

This work introduces an extensive critical review of the available planning techniques and addresses the problem of planning for site operation and control.

Based on the outline of the nature of site control, this research developed a simulation based network model which combines part of the logics of both VERT and CYCLONE. Several new nodes were designed to model the availability and flow of resources, the overhead and operating cost and special nodes for evaluating time and cost.

A large software package is written to handle the input, the simulation process and the output of the model. This package is designed to be used on any microcomputer using MS-DOS operating system.

Data from real life project were used to demonstrate the capability of the technique.

Finally, a set of conclusions are drawn regarding the features and limitations of the proposed model, and recommendations for future work are outlined at the end of this thesis.

KEY WORDS : Network Analysis, VERT-CYCLONE, Costruction Management

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Chapter One

Introduction And Background

1.1 Introduction :

The construction industry plays a major role in the economic growth and development of any society. Construction projects in general, and capital project in particular, are undertaken in all parts of the world as an essential development to improve standards of living, satisfy the needs of society and to increase business efficiency.

A project, and construction project in particular, can be defined as a non-routine, non-repetitive one-off undertaking, normally with discrete time, financial and technical performance goals.

In his book [8], R.D.Archibald noted that:

"... given unlimited time and cost resources, the construction industry could produce any project conceivably needed by society.".

But while engineers and technology may possess the ability to design and construct for our needs they have always experienced problems in producing them within mandatory constraints of time, cost and quality, and experience shows that most construction projects which run into trouble do so for reasons related to managerial or financial factors rather than practical or technological problems [12].

Civil engineering and building contractors have implicitly used the concept of project-centred contract management for many years. In the past, and before the introduction of the Gantt Chart, they used to rely on experience, intuition, and common sense in time tabling project activities and managing resources. There is no record showing any sign of using any formal procedure or technique in this area of management.

The start of the second half of this century saw a considerable change. The inflation, the growing needs of modern societies, the changing economic environment, and the size and complexity of new projects led to the belief that the traditional ways of managing the production of our needs were no longer valid, and a different approach to the organization and control of the available resources for project development was needed.

Since the 1950s, much work has been done in many different areas of management theory and technique. New terms and concepts such as: Project Management, Construction Management, System Analysis, Operation Management, Operations Research..etc have emerged to mark the start of a management revolution aimed at improving productivity and efficiency.

The late 1950s saw a major qualitative development in the field of planning and control with the introduction of the network analysis. The application of this technique spread very quickly to a variety of fields, and for the last three decades it has dominated the area of project planning and control. Since the introduction of the network concepts the model went through several stages of development, new logic and features have been added to enhance its capability, and each advance has led to new acronyms (Decision C.P.M., GNA, GERT, CYCLONE, VERT....etc) and defined areas of application.

In the early 1960s, the original model(i.e.C.P.M/PERT) was transplanted into the construction industry and adopted as a means for planning and controlling increasingly complex projects. Fairly quickly major shortcomings in the model were recognized, and many (perhaps a hundred) mathematical and heuristic rules (algorithms) were developed to be used as a complement to the model to overcome some of its deficiences.

During the 70s and early 80s the development of network analysis continued and the use of the original model was strengthened by the advances made in computer technology. Despite these advances both in hardware and software, practitioners have been and are still facing serious difficulties in applying the original model for construction planning and control especially at the site level.

F.L.Harrison [61] (pp-141), mentioned that:

> "...even in the late 1970s, contrary to all the publicity and literature produced on C.P.M/PERT, many companies were actually discarding C.P.M/PERT and returning to the use of bar chart, even on large and complex projects."

This observation with many others raises a very serious question: is the network model suitable for the construction industry?

The literature available has different opinions some of which are conflicting. Strangely enough, J.M.Antill and R.W.Woodhead [6](pp-1), described C.P.M.

> "as a powerful, dynamic tool for the planning and management of all types of projects. It is admirably suited to the construction industry. "

While other writers like G.S.Birrell went to the other extreme, in his article [18], he said:

> "...the basic critical path network technique is neither a true model nor the best approximate model of the construction process.".

These two extremes may be exceptions because the majority of the criticisms agreed that the network model suited the upper level of management in setting targets and monitoring progress at an aggregated level, but it failed to consider the dynamic nature of day-to-day management at the site level. This criticism seems reasonable as it acknowledges the advantages of the model and is in line with the real world application and field experience.

From the literature, as we will see later in chapter two, it is clear that the development of the network analysis has always been directed towards satisfying the needs and the requirements of managing research and development projects. These projects are usually undertaken by the manufacturing industry, and in many cases, financed and controlled by military organizations. Researchers and practitioners throughout the network development tried to use each advanced version for construction planning without considering the special nature and the characteristics of the construction projects. In this sense it would appear that people were trying to fit construction planning and site management problems to the available technique.

Contrary to that, and as is well known, understanding the nature and the aspects of the problem is the basic step in conducting any kind of operations research exercise. This understanding is essential for choosing the right approach and for adopting or developing a valid model or technique which can represent the problem and provide workable, useable and satisfactory solutions.

1.2. Objectives :

The main aim of the present work is to develop a network technique which keeps the advantages of the original model and meets the requirement of detailed planning at the site level. In the proposed model the emphasis is put on developing a flexible structure and logic to enable the planner:

- To model the way the site management thinks when managing and controlling their resources.
- To simulate the site environment.
- To link the detailed plan which serves the management on site with the summary plan which serves the top level of management.

In this research a portable software package is developed to handle the input, the simulation process, and the output of the model. This package is designed to be run on any microcomputer compatible with IBM machines and which uses MS.DOS as an operating system. The proposed model is applied to a real life project. This application is introduced to demonstrate the capability and the practicability of the technique, and to show the difficulties which may arise in practice.

To ease the introduction of the critical review of the available planning techniques in chapter two and the problem definition in chapter three, this chapter introduces a brief idea of background on the following:

- Nature and aspects of construction projects.
- Project life cycle.
- Management functions.
- Project Breakdown Structure and basic definitions.
- Types of plan and the current practice at the construction phase.

1.3. Nature And Aspects Of Construction Projects :

They can be summarized as follows:

1-Construction projects continue to grow in size and complexity as technology advances, which in turn generates the necessity of specialization [2]. Nowadays, especially in a large project, it is normal to find several specialists involved such as: structural, construction, services, safety and system engineers. Each is responsible for his specialized technology and perceives the project differently. Obviously, this situation often creates a breakdown in communication and thus organizational interface problems [2,97]. co-ordinating and directing the efforts and the skills of those involved towards the same set of project objectives, especially at the construction phase, can prove to be a very difficult task to achieve. It requires reliable information, effective communication systems, valid techniques, and high quality management.

2-Unlike the manufacturing industry, the construction project usually involves several separate parties (owner, designer, contractor, and subcontractors) with conflicting goals. For example, the main goal of the owner is to get a facility with a specific quality, within a time limit and at a predefined price. While the aim of the contractor is to construct the facility with minimum input and with least acceptable quality which minimizes his cost and maximizes his profit. The completion time in this case will exceed the time limit and the quality of the final product will undermine the quality specified by the designer. In this situation it is very difficult for the planner to satisfy the owner requirements and meet the aim of the contractor at the same time.

3-A construction project is unique. It has uniqueness of design, time, personnel and economies of scale. Its activities have not been and will never be identical with those which have occurred before [67,97]. Even within the same project, activities of the same type are never conducted with the same magnitude and under the same exact environment. In other words mass production simply does not exist and activities are not as repetitive as those in the manufacturing industry. This feature of singularity does not lend itself as easily to effective control of quality and productivity as in the manufacturing industry. It makes the production process of the construction phase very difficult to model and control.

4-The production process of the construction phase is unique and quite different from that of the manufacturing industry. In the manufacturing industry each trade or craft has its own workspace which is not shared with any other trade. The craftsman is usually stationed in one or a limited number of locations on the production line. He performs a specialized activity with a fixed magnitude repeated all the time under a controlled physical environment.

In this situation, and since each trade has its own workspace and the amount of work involved in its activity is fixed, modelling the sequence and the logic of the production process, defining the rate of production, estimating the time duration of each activity and balancing the amount of resources to avoid any idle time are straightforward.

The situation in the construction project is quite the opposite. Each part of the final product has to be produced in a specific location in the project. So each trade as a server in this type of queuing system has to move continuously from one location to another to perform the same type of activity, but very often with a different magnitude and certainly under different physical conditions. In many cases the trade has to make special arrangements and even use different technology and methods to perform the same type of activity in a different location in the project.

For example, in a tower block building, building an external wall in the ground floor does not require any special safety arrangement for the workspace, and the required material does not need any extra handling. While building the same type of wall with the same specification on the 20th floor requires special safety arrangements and perhaps different skills, also the required material has to be lifted to the work location. This means more resources and time are needed for the same type and amount of work.

This situation makes defining the activities of each trade together with the required resources and skills, and estimating their time duration and cost a very complicated process. It requires skill, experience, and high quality judgement.

5-From the description introduced in the previous section the production process can be seen as a set of production lines interacting with each other, each represents the flow of a specific trade or resources. The interaction between these lines, in some cases, is confined only to overlapping where it is possible for more than one trade or resource to share the same workspace. While in many cases these lines merge and the technological logic and constraints on the space do not allow the sharing of the same workspace. in these cases the flow of some trades will be interrupted and the resource involved has to stay idle pending the release of the necessary workspace.

This special nature of the production process makes modelling the sequence of the construction activities and defining the way of proceeding a very difficult task indeed. Also it makes balancing the level of resourcing to provide a continuity of work for each trade not only difficult but in some cases a near impossibility.

6-Construction projects are affected by the environment surrounding the production process. Inclement weather, changes of site conditions, late arrival of materials to site, fluctuations in productivity, and many other factors have an impact on project progress and resource performance [2,12].

In practice, as is well documented and because of these factors, it is rare for the construction operation to reach a steady state of productivity, because interruptions, disruptions and productivity gaps are the rules rather than exceptions in the industry [2,15].

Under these conditions the uncertainties entering the projected time and cost estimates are likely to be of greater magnitude and impact than would be the case in most other production contexts.

7-Today, engineering design is done by computer, so the design time is cosiderably reduced [2]. This means that more organizations can quickly place more designs in the market, and more emphasis will be put on the importance of the timely completion of the project.

8 - Construction projects have their own special personnel problems:

A. For the contractor it is not easy to maintain a constant workload for his staff in a particular location. He has to obtain new jobs in any possible location. This means that the project planner must constantly face the problem of forecasting performance in unfamiliar locations and conditions [97].

B. Most projects have on-line personnel. Construction staff are usually hired or brought together for a particular project. Turnover rates tend to be high and in many cases, to secure continuity of employment, men familiar with specific jobs leave before completing their work in the project.

Obviously, this results in the need for recruitment which is always costly, and the continuity or stability of the learning curve decreases.

Under these conditions, the relationship between the supervisory personnel and hand-on crews at times becomes casual despite crews and supervisors being members of the same organization. Dispersal of personnel at the completion of their parts disperses accumulated knowledge and experience, and loses the benefits of training [2,67].

9-The cost of capital is very important for both owner and contractor, because tying up capital unproductively results in unnecessary extra cost [2], and the main aim must be always to make the investment productive as early as possible.

To achieve this, the contractor usually attempts to bring and deploy the required resources only when they can be effectively utilized.

The owner, on the other hand, puts more emphasis on his target date, and more pressure for an early completion of the project. For the owner, if any sort of delay happens, it may result in heavy losses due to the failure to meet the demand which led to the investment in the construction facility [3,12,67].

10-For survival, contractors in general rely on the optimal use of their limited resources, for which they must continually procure new projects to cut their indirect costs and keep their staff occupied and productive. To capture the market they usually economize on their present projects and move the available limited resources to the new projects acquired from the market [2,3,67].

Because of this and the dynamic nature of the construction environment it is often very difficult or undesirable for the contractor rigidly to follow the original plan and the resource schedule.

This means that such plans and resource schedules have to be particularly flexible in their structure and sensitive in their analysis to all possible changes.

11- On a large project the interrelationship between activities and the interaction between resources are complex. Dynamic decisions and continuous corrective actions on site are necessary to keep the project on schedule and meet targets.

The necessary information to make these decisions is so large. The site management, in making them, usually relies on experience, intuition, and judgement which are not always sufficient for making the right decision at the right time.

This situation requires that the plan should be able to represent the management policy and to state the project targets at each stage.

This helps the management to concentrate only on the trouble areas thus reducing the number of decisions which in turn reduces considerably the amount of necessary information.

1.4. Project Life Cycle :

Any project has a life cycle. It consists of several distinct phases and each has identifiable start and end points sometimes overlapping. The project passes through these phases as it matures, and each phase produces a new and different product as well as information which form an input to the next phase in the cycle.

During this process the rate of expenditure of resources increases with the succeeding phases until a rapid decrease occurs sometime before the completion of the final phase. Generally, the life cycle of a construction project has the following major phases:

-Conception.

-Design.

-Procurement.

-Construction.

-Move-in or start-up.

-Operation or utilization.

Since this work is concerned with detailed planning and control at the site level the argument will be focused on the construction phase.

At this phase the designers` plans and specifications which represent the needs and requirements of the owner are converted into physical structures and facilities. It is the backbone of the project life and without it the project is simply a collection of documents, plans, and statements of hope.

Generally, the key roles at this stage are played by the contractor, suppliers, and subcontractors, and the success of any construction project depends on how well this phase is planned and carried out. Usually, this phase involves a large number and variety of people . It needs skills to organize and co-ordinate all the efforts and the required resources. The skills and efforts needed depend actually upon the size and complexity of the project.

For example, the variety of technologies and types of construction involved, the required quality standards defined by the designers, the geographical location of the site and work environment, the management skills of the contractor...etc.

1.5. Management Functions :

Management, in the context of this work, refers to the practice of organizing human activity. It is a social exercise, whereby a number of individuals are organized and motivated to achieve common purpose and goals [51,21]. It is concerned mainly with the ways and means that regulate an enterprise and co-ordinate the efforts of the personnel involved to achieve predefined targets and goals. The main functions of management at any stage of a project are: planning, scheduling, and control.

1.5.1. Planning Function :

Planning is the process of modelling a situation which is to be enacted sometime in the future. It is a mental exercise, whereby the planner decides, in advance, who does what, how, and by what means?.

The main objective of the planning activity is to optimize the utilization of resources according to a set of restrictions, and to find the best compromise between conflicting goals (e.g. time and cost targets).

Project planning, in particular, is the enumeration of the activities associated with the project and the determination of the order in which they must occur [30]. It is the process of choosing one method and order of work to be adopted from all the various ways and sequences in which it might be done [6]. It also includes the establishment of resource requirements and the setting of standards and targets to be achieved [57].

The planning process is always subject to many constraints such as: the completion time, the availability of required resources, the quality standards...etc. The aims of planning are:

- To offset uncertainty by determining, in advance, an acceptable sequence which takes into account the possible consequences of various courses of action.
- To focus attention on objectives and facilitate control by setting standards and targets against which the actual progress can be measured and judged [12].
- To minimize the input resources to gain economical operations. This is done by balancing the amount of resources to provide a continuity of work for each of them which in turn reduces the idle time and improves productivity.

The planning activity needs skill, knowledge, and experience. It is both a science in its use and development of new techniques, and an art in deciding when to plan and what technique to use.

1.5.2. Scheduling Function :

While the planning process decides who does what, how, and by what means, the scheduling process decides, in advance, when all these future undertakings should take place.

Project scheduling, in particular, is the determination of the timing of the activities comprising the project and their assembly to give an overall completion time [6]. It involves the translation of the plan into a timetable by assigning a time duration for the accomplishment of each part and section of the project [16].

1.5.3. Control Function :

The main objective of the control function is to keep the project on schedule and within the planned budget. Since planning is to prepare for the future, this mental exercise will not play its full part unless it is followed by proper control.

Project control is the process of implementing the plan and the schedule. It includes monitoring the actual progress and performance, comparing them with plan targets, defining schedule and cost variations, undertaking proper corrective actions and modifying the original plan if necessary to achieve the predefined targets [6,35,57].

In order to achieve its objectives, control at the construction phase should ensure the following:

- Proper resources are available in the right place at the right time.

- The relevant field decision-makers and agents are properly briefed as to what has to be done, when, and how.
- Resources are used effectively.
- The resulting work output meets all contractual and quality requirements.

From what has been explained so far planning, scheduling, and control can be seen as a continuous process within the same operation. In reality these functions constitute a cycle of activities. Throughout this cycle, management:

- Defines the immediate objectives and criteria.
- Sets targets by planning and scheduling.
- Monitors performance against targets.
- Assesses alternative solutions and strategies.
- Decides the required actions and re-plans if necessary.

This cycle is conducted formally and informally by management staff at all levels and repeated daily throughout the project life especially at the construction phase.

1.6. Uncertainty At The Construction Phase :

Reliable forecasts of project completion time and cost are a major concern of management. Reliability is dependent upon the accuracy of the sequence logic of the plan, the individual activity duration estimates, and the variables related to the project environment. Because of the special nature of construction projects (see section 1.3), there are many uncertainties that affect the activity duration and production process [4]. They can be classified as:

- Variability in the performance.
- Interference from outside which frustrates progress.

1.6.1. Variability :

This concerns internal variations in the time duration of individual activities due to variations in productivity. These differences may occur for one or more of the following reasons:

- In each dicipline or trade there is a wide range of capabilities, different skill levels, and different degrees of fatique and motivation.
- The time when the activity is to be carried out.
- The nature of the place where the work is to be done.
- The crew composition.
- The safety measures and arrangement.
- The management style and capability.

All these factors affect worker performance and produce the normal variations found in practice.

These variations are random in nature, and produce a range of possible time durations for each activity. This range can be represented by a probability distribution during time estimating process.

1.6.2. External Interference :

Many external variables interfere with production on site, interrupting or even halting the progress of construction activities. They originate from several sources [12,13,24,80,108] :

- Design changes.
- The late running of an activity on which the start or the progress of another is dependent or from which resources are due to be transferred.
- Weather conditions.

- Labour unrest.
- Labour absenteeism.
- Unavailability of special tools, equipment or specific types of material.
- Mistimed delivery of materials.
- Space congestion.
- Unexpected sub-surface soil conditions.
- Poor instructions which entail re-working.
- Theft and vandalism.

1.7. Project Breakdown Structure And Basic Definitions :

Almost every textbook on construction planning and control devotes at least one section to the concept of Project Breakdown Structure(P.B.S.). In practice the process of breaking down the structure of the project into its basic elements is conducted formally and informally to ease estimating and planning processes.

This step is necessary for the estimator to produce a reliable cost estimate for each part of the project, and for the planner to design a workable plan and schedule. In the last decade, the concept has been recognized as a proper method for estimating costs at all stages, because it can relate the engineering cost estimate(which is based on the functional element) to the construction or operational cost estimate(which is based on trade classification and activity concept) [2,136].

Also it is adopted for the design of a computerized cost estimating system. The Project Breakdown Structure(P.B.S.) is defined by R.D.Archibald [8] as follows:

> "It is a graphic portrayal of the project,exploding it in a level by level fashion down to the degree of detail needed for effective planning and control."

The level of detail and divisions depends on the size and complexity of the project itself.

With this concept, a large project can be divided by location into small projects called sub-project, each in turn can be subdivided into parts and sections, each called a workpackage. Each workpackage can be broken down into parts, each having a specific function in the structure of the project. Each of those small parts is called a functional element which is the centre of the (P.B.S.) concept.

The division can be carried out further such that each functional element is divided into sub-element and further into what are called work items. A map of this hierarchical approach of divisions is shown in figure(1-1), and a simplified example of a multi-storey office building is shown in figure(1-2) to clarify each of the following definitions:

1-Workpackage:

Workpackage is a major part or section of a project or sub-project identified in a specific location. It is usually made up of a set of functional elements producing part of the construction facility. It depends on the level of detail, workpackage can be a single activity, several activities in series, several activities progressing in parallel or a mixture of both. It may be conducted by one organization, one specialized department, one or several trades and crews(see figure 1-2).

2-Functional Element :

Functional element is one part of a workpackage, its physical end product has a specific function in the structure of the project. It may consist of one or several parts, each is called a sub-element. A functional element may represent one or more activities which may be conducted by one or several specialized crews or trades(see figure 1-2).

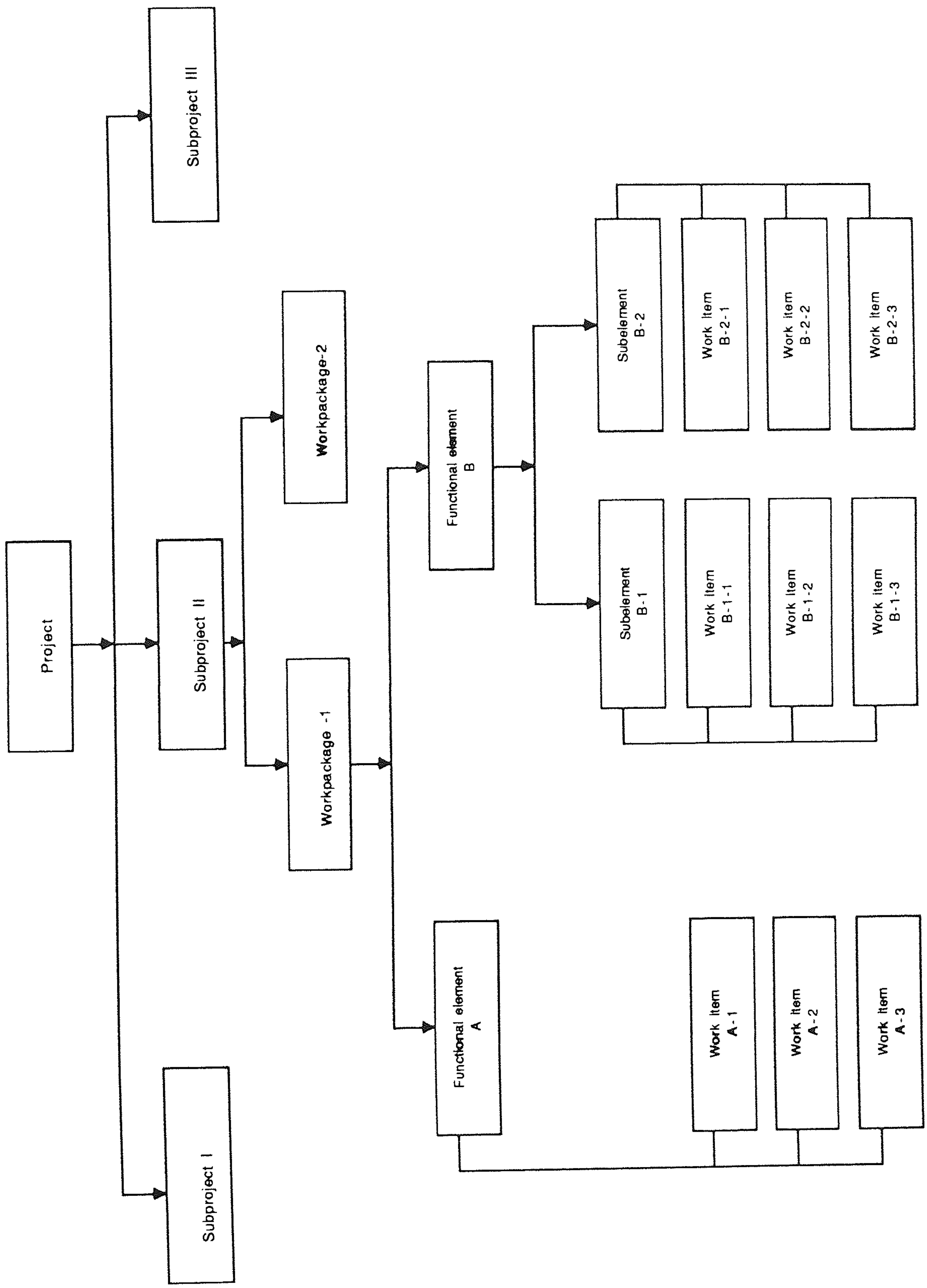


figure (1-1)- Project Breakdown Structure (PBS) Chart.

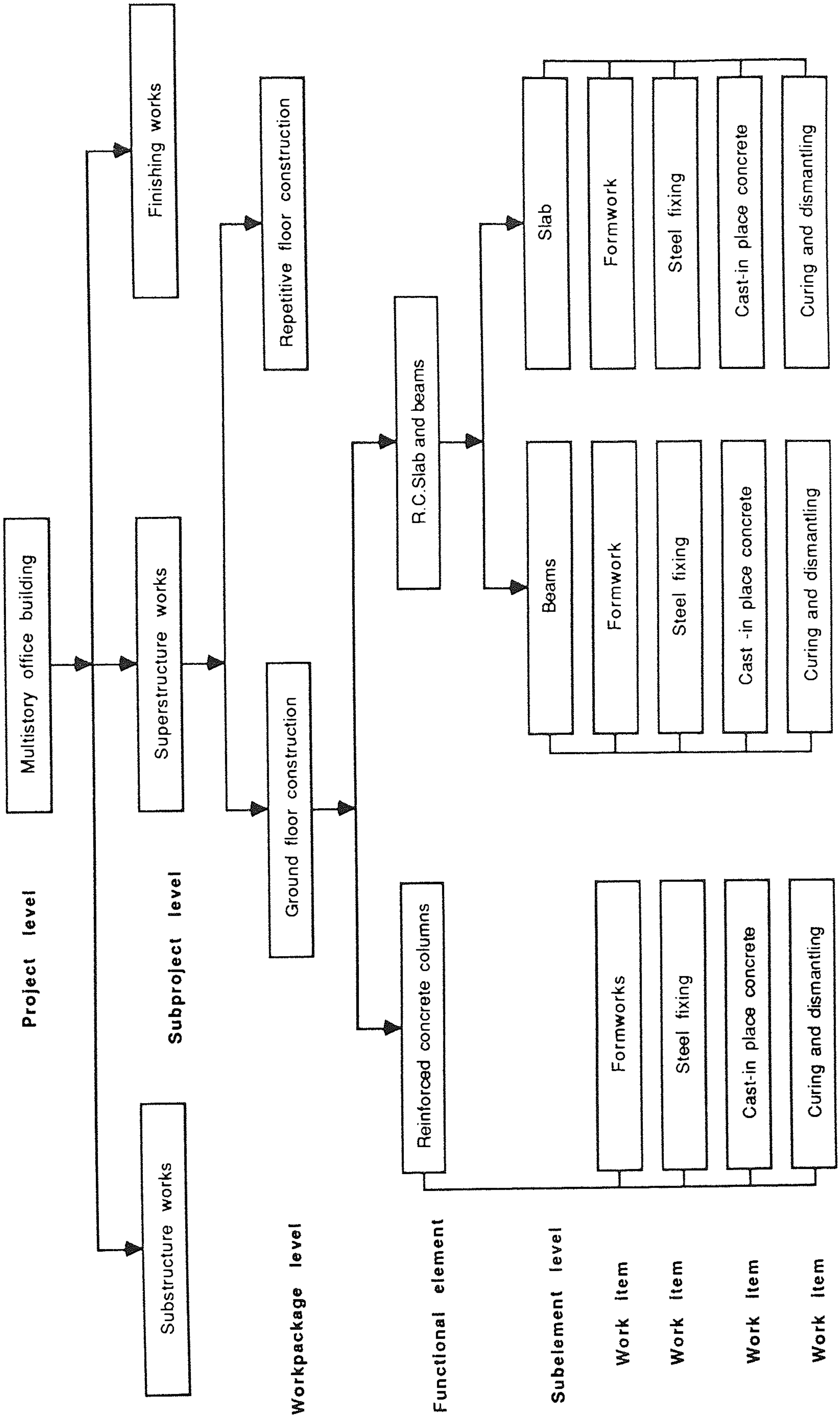


figure (1-2)- Part Of PBS Chart Of Multi-Storey Building.

3-sub-element:

sub-element is one major component of a functional element. It may be conducted also by one or several trades. Depending on its nature, it may represent part or a whole of one activity.

4-Work Item :

Work item is the smallest possible division of a Project Breakdown Structure. It is one ingredient of a functional element or sub-element, and represents part of the activities of a specialized crew or trade (see figure 1-2).

It is easy to see from the example (figure 1-2) that many functional elements and sub-element may have the same type of work items (e.g. the formwork item in the R.C.Columns, R.C.Beams, and the R.C.Slab). This facilitates the process of estimating the cost of each trade and provide a continuity of work for them in the plan.

At this point, it is necessary to mention that the Project Breakdown Structure(P.B.S.) does not develop in full detail at any one point in time, but starting at the conception phase gradually develops in detail as the project proceeds through the design and construction phase [2].

Activity, Operation, Process, And Work Task

These terms tend to be used interchangeably in the daily activity in the construction industry. Before introducing the concept and the analysis of the CYCLONE technique, Halpin and Woodhead, in their textbook [58], provide clear definition for each of these terms.

At this point, a simple example from figure (1-2) will be helpful in clarifying the meaning of each definition. The functional element (Ground floor construction) of the workpackage (Reinforced concrete columns) in figure(1-2) is taken and expanded in figure (1-3). In this example, R.C.Columns in the ground floor can be considered as an activity, and each of the work items (i.e. formwork, steel fixing, cast-in place concrete, and curing and dismantling formwork) as an operation. Each of these operations usually consists of a set of undertakings, each called a process.

For example, the cast-in place concrete operation (figure 1-3) may comprise three different processes: concrete mixing, concrete delivery, and placing concrete and finishing. Each process is made up of several small jobs, each called a work task. For example, the concrete mixing process (figure 1-3) may have a set of four work tasks:

- Move aggregates, sand, and cement to the mixing place.
- Load the mixer with ingredients and water.
- Switch the mixer on and off and watch.
- Unload the mixer to the crane bucket.

Now it is easy to introduce a definition for each term within their hierarchical structure (figure 1-3).

5-Work Task :

This is a basic task assigned to a crew or trade member. If it is broken down into its components, micro-analysis of human and equipment motion will be involved. The time scale may be measured in minutes or even in seconds.

6-Process :

A process is a unique collection of work tasks related to each other through a technological structure and sequence (e.g. the concrete mixing process in figure (1-3), and represents an identifiable segment of an operation. It can be one of the many processes that a single worker can perform because of his training and skills.

Many of the construction processes are highly repetitive (e.g. concrete mixing process), where a crew member cycles through a set of work tasks processing or using resources and achieving progress in construction. The time scale is measured in minutes or hours [58].

7-An Operation :

An operation is a collection of work tasks and processes which involves the commitment of resources within a specific technological format or methodology that leads to the placement of a construction component [58]. The full description of a construction operation requires the identification of the technology involved, the enumeration of, and allocation of the required resources to the work tasks and processes involved.

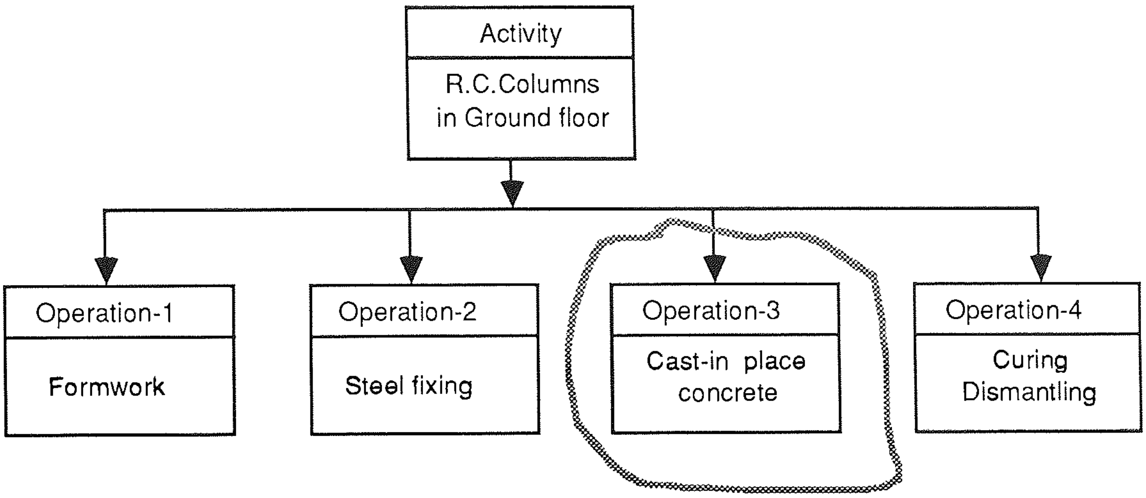
For example, the cast-in place concrete operation (figure 1-3) can be performed by using a concrete pump instead of a concrete bucket, and ready-mixed concrete from the central plant instead of mixing concrete on-site...etc.

Construction operations and processes are often common to many activities, and in many cases are performed by the same specialized crew. When an operation is performed at a specific location in a project, it assumes a unique significance and magnitude, which in turn defines a part or a whole of specific activity. Many of the construction operations are repetitive, and the duration scale of their cycle is measured in hours or days.

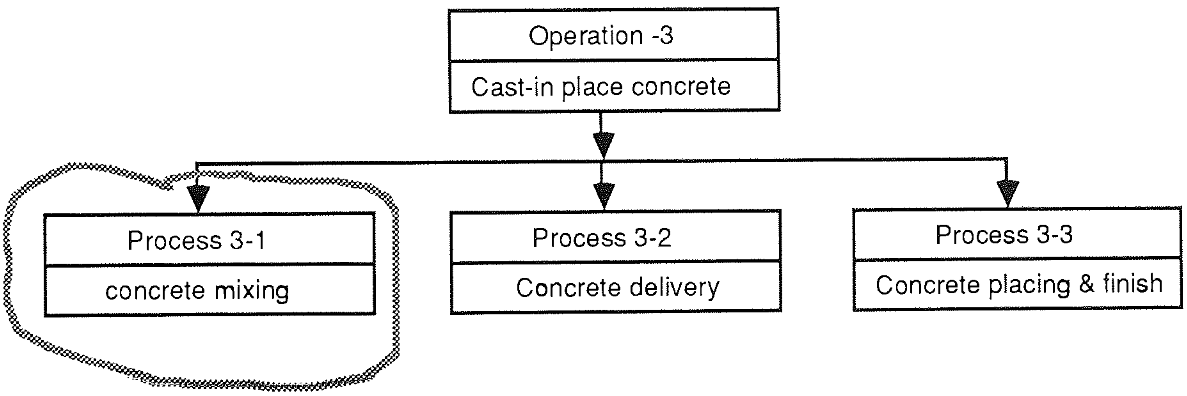
8-An Activity :

An activity is an undertaking which may consist of a set of operations and processes consuming time and perhaps other resources [47,123]. It is an element which is normally defined by a planner, estimator or cost engineer. It may refer to an

Project : Multi-story office building.
Subproject : superstructure works.
Workpackage : Ground floor construction.
Activity : all R.C.Columns in the ground floor.



Operation-3 : Cast-in place concrete using 1/3cu .y mixer, crane, one foreman, three operators, three carpenters, and nine labourers.



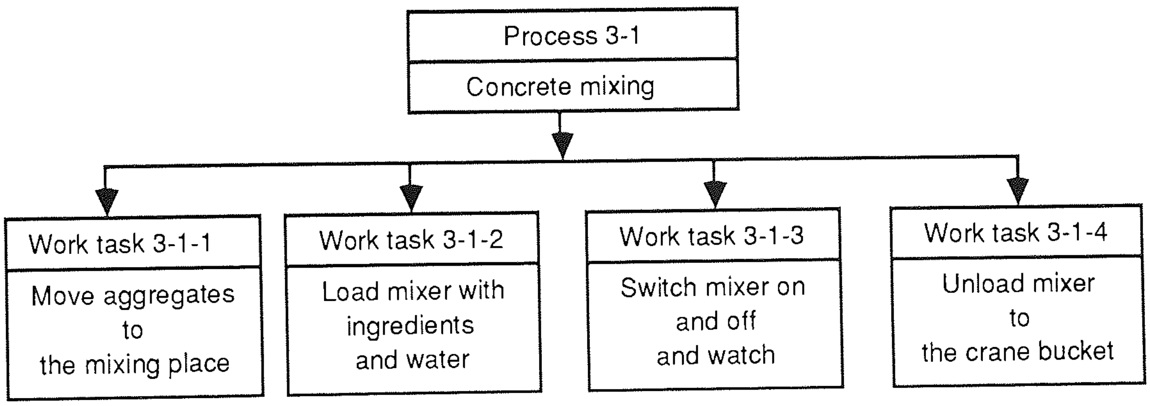


Figure (1-3) : An Example On The Concept Of Activity, Operation, Process, And Work Task.

actual item of work listed in an itemized bill of quantities or to a portion of the project defined by contract drawings.

It is a unique undertaking in a specific location with defined magnitude. It is concerned with a physical segment unique to the time and cost control of the project. The time scale of an activity is measured in days, weeks or even months.

9-An Event :

An event is a well defined occurrence in time [47].

10-Milestone :

A milestone is a very important event in time. It may mark the start or completion of a major section of a project or a workpackage which may involve a major resource commitment.

1.8. Types Of Plan And The Current Practice At The Construction Phase :

Generally, the construction phase is achieved through the contracting system, and planning and scheduling for this phase are usually the responsibility of the contractor. In some cases, where the owner has an in-house construction capability, this phase is conducted by his organization, and the responsibility for planning and control lies in his hands.

In the contracting system, where there is a single contract for the project, the general contractor will be responsible for all planning and scheduling problems and solutions [61]. In other cases, where the owner has to choose several specialized contractors, he will be responsible for co-ordinating the work throughout the construction phase.

Within the contracting system, the contractor is usually invited to bid for this phase. He receives the contract document, prices the work and submits a tender within a predefined period of time. At the tendering stage, contractors may or may not prepare a plan and schedule for the project work. This is dependent upon the size and complexity of the project and the contract conditions.

For small projects, formal plans may not be prepared especially where the contract conditions did not make a specific requirement.

For large projects, the plan and schedule are usually prepared in summary rather than in detailed form. This is largely due to economics, as contractors expect to win only between 10-20 percent of the jobs they bid for [67,105].

Resources expended on planning jobs not acquired are largely wasted. This increases the overhead cost, which has to be recovered from future job, and in turn decreases the chance of winning new contracts. Another reason for not conducting detailed planning at the pre-tendering stage is that, the tendering period is usually very short and does not allow the contractor to gather enough information for detailed planning [61,67,105].

Within the contracting system, generally four types of plans and schedules can be identified: Pre-tender plan, Pre-construction plan (master plan), Construction plan, and stage plan.

1.8.1. Pre-Tender Plan :

The main purpose of this plan is to focus the minds of all concerned on realistic procedures and timing for carrying out the construction works. In some cases the owner prepares it in order to permit developing the work in a way that satisfies his needs and requirements. In this case the plan becomes part of the contract documents, showing prospective contractors the work phases and conditions.

The contractor prepares this type of plan to enable him to appreciate the importance of time and resource considerations. It helps him to foresee problems in order that he can work around and develop special phasing for the work and choose economical methods of working. In this case, he can produce realistic time and cost estimates for each part of the project, and he will be more confident in pricing the work, which in turn increases his chance of tendering successfully.

This plan outlines the project in skeletal form. It is a summary plan showing only the major parts and components of the project. The level of detail depends on the complexity of the project. It may be confined to the workpackage level (see section 1.7.1) or it may reach functional elements and sub-element levels (see sections 1.7.2; 1.7.3). The estimator relies on this type of plan to estimate the cost of each stage of the project because it helps him to appreciate the difficulties of the work at each stage.

This plan contains approximate estimates of the overall timing of each stage and a rough estimate of the required resources. Should the contractor win the job, this plan provides the base from which more detailed plans can be developed.

1.8.2. Pre-Construction Plan (Master Plan) :

When the contract has been won, further information will be available from the client and his consultant, and within the contractor's organization resource requirements become immediate. Also, suppliers and subcontractors may face changed conditions and commitments.

In the light of any changes, the pre-tender plan will be amended and then carried forward as a pre-construction plan (master plan). At this point the pre-tender plan, depending on the size and complexity of the project, may keep its level of detail or it may be expanded to clarify more complicated interrelationships which might have been missed at the tendering stage.

The pre-construction plan is used throughout the construction phase by senior site and general managers as a reporting and review document. It is also intended for use as a guide for decision making and control at this level.

1.8.3. Construction Plan :

In this plan, all the activities of each stage in the pre-construction plan are expanded and developed in great detail. It usually shows the sequence of activities and events that determines the contract period as well as the detail of their interaction. It also shows in more detail the interfaces between the construction stages and their interrelationships. The level of detail in this plan depends on the size of the project. If it is relatively small the level of detail usually reaches the level of work items (see section 1.7.4) and this plan will represent the final details of planning.
In this case, it will serve the lowest level of management on site as well as the middle management.

On a large project the level of detail will reach only the level of sub-element (see section 1.7.3). In this case, this plan is used throughout the construction phase as a middle management decision and control tool. It helps in developing an approximate profile for the required resources at each stage of the work, providing more information regarding the work, mobilizing resources to initiate production, checking performance, and providing control.

This plan usually adjusted and modified in the light of any major changes in progress. Together with the master plan provide a base for developing all the necessary stage and periodical detailed plans where needed.

1.8.4. Stage Plan :

This type of plan is prepared when the project is relatively large and complicated. When the project is small the construction plan will do the job of this type of plan. It usually covers a stage or part of the work defined in the master plan. The span of its duration usually coincides with the interim payment or with the time space between two consecutive milestones defined in the master plan and the construction plan.

The plan serves the ends of junior managers. It helps them in managing day-to-day and week-to-week activity. It takes into account resource limitations at the period which it covers and the interrelationships, and tries to secure a continuity of work for all resources, avoiding idleness and developing economical operations. It enables management to exercise greater control over site operations and provides a basis for monitoring progress, defining variations and modifying the main construction plan if necessary. This plan must indicate its relationship with the master plan and the main construction plan through common control points.

Chapter two

Critical Review Of The Available Planning Techniques

2.1 Introduction :

During the last three decades thousands of textbooks and articles have been written on planning techniques and network analysis and their applications in different fields and industries. Throughout the literature each technique has received plenty of criticism regarding its structure, analysis, and suitability for each type of application.

This chapter will introduce a brief review of the development of each technique together with the major criticisms of its application in construction planning and control.

The main deficiences of the structure and the analysis of the original version of the network model will be expanded in more detail in chapter three when introducing the problem definition and the scope of the present work. Each planning tool has advantages and disadvantages regardless of its focus. In this chapter, each of the planning techniques will be evaluated with respect to three main criteria :

-How well it documents the thinking of the planner and captures his attention and the constraints that influence him when modelling the real world.

-How well it communicates the planner's thinking to the people charged with the execution of work.

-How easy the language of its symbols, notation, and the output of its analysis is to the people on site.

Planning models or techniques can be classified into three categories :

- Basic models.
- Hybrid models.
- Advanced models.

Basic Models

2.2 Bar Chart :

Little is known of formal planning and scheduling methods before the beginning of this century. During the 1st world war, one of the early management consultants, Henry.L.Gantt introduced the idea of the interplay between planning and control [90]. As a result, he designed a chart to show the relation ship between promises and performances.

In 1944, the Ministry Of Public Buildings And Work published a paper entitled "performance and progress chart". At this point the bar chart emerged as a planning and controlling aid for construction works. Lockyer [82], suggests that this is the first formal scientific consideration of the problem of work scheduling and control in the construction industry.

The main reason for the rapid adoption and continued application of this technique is the simple way in which the chart displays the plan [50]. It is clear, simple, and intelligible to all levels of management and supervision [2,12,22,61, 90], and with little training anyone can learn to construct and use the technique [53]. It is easy to update and the follow-up is straightforward [133].

Later, however, as management had to deal with larger scale and more complex projects, some limitations and handicaps of the method become obvious :

- It fails to model the precedence relationships, interdependencies, and interfaces between activities. in small projects, this is may not be serious as the planner can remember the main links between activities, but even in this case the planner has to document those links in writing in order that people on site can understand them and follow them up. This is not possible on large projects and the bar chart is then of limited value [50,61,90].

- It fails to display the volume of work related to activities, to model the flow of resources, to indicate which of the activities affect the completion time of the project or those which are able to benefit from the buffer time.
- It is not an analytical technique.
- It is not able to handle uncertainties.

Bar Charts, nowadays, tend to be restricted to small , simple projects, however, they are generally used as a means of communicating the output of more detailed analytical planning techniques.

2.3. Matrix Schedule :

The matrix schedule is designed for planning and controlling the construction of high-rise buildings with successive floors repeating the plan [12]. The structure of the schedule using this method is simply a cross section or elevation of the building itself. The horizontal rows correspond to floors, starting with the basement level and working up to the top floor. The vertical columns correspond to the activities to be performed on each floor.

Each activity is scheduled by a box which is divided to show the scheduled start and finish date with the expected duration, and it provides space for actual dates to be entered in the field. The major advantage of this method over the bar chart is that the logical interrelationships among activities are represented. The technique has clear presentation, is understandable to all people involved and is easy to construct and use on site.

The problems with this method are:

- It is not general, it can be used only for high-rise building.
- It is not general, so it can not show which of the activities affect the completion time of the project as a whole.
- It can not handle uncertainties

2.4. Line Of Balance(L.O.B) :

This is a graph displaying the unit completion of work against time. The technique was developed during the second world war and described in its present form in 1962 [23]. It is basically designed to be used in the manufacturing industry for planning and controlling the production of repetitive units [39,40,75,104,137]. In 1968, one study [124] greatly modified the basic concept of L.O.B and applied it to house construction scheduling.

The main idea of L.O.B is to design production lines for a project, each component of the line representing a particular activity. After defining the completion time for the project as a whole, the technique will balance the flow rate of all lines by deciding the number and the size of the crew for each line to provide a continuity of work for each trade.

Throughout the consideration of using the technique in the construction industry, several versions emerged each with slight variations from the original concept, but all these versions are based on the same resource oriented principles [18,72].

These versions appeared in the literature under different names: Line Of Balance Schedule [10,23,60,84,109,124], Vertical Production Method (V.P.M) [104,105,106], Time-Space Scheduling [107,133], Cascade Chart [127], Velocity Diagrams [129], and the best known technique, the Linear Scheduling Method(L.S.M) [10,66].

The variation of each of these methods is designed to suit specific applications such as: multiple housing schemes [11,23,129], high-rise buildings [58,104,106], and linear construction projects (e.g highways, roads, railways, pipelines and tunnels) [44,71].

The L.O.B technique and the derived methods are easy to apply and understood. Their major contribution is their attempt to model implicitly the flow of resources and balance the rate of production of different trades. However, the technique has limitations imposed by its structure. That is that the amount of work involved in each activity in the project must be expressed in terms of unit completion. This has restricted its application to high-rise building, housing schemes, and linear construction projects which have a common production unit.

Despite the success reported in part of the literature there is a doubt that L.O.B in general is well suited to repetitive projects. This is due to the following reasons:

- Repetitive work is only part of the construction project (e.g. roads have culverts and bridges at discrete points on their routes.), so the technique on its own is not appropriate for significant sections of the work.
- Because of the unique nature of the construction activity (see sections 1.3.4 and 1.3.5), truly repetitive work in an absolute sense does not exist. The amount of work involved in the repetitive activities is never exactly the same.

- Resources, particularly equipment, may not be exclusively devoted to a specific component of the production line as it might be expected to be in a manufacturing process, and L.O.B is not able to handle this situation.
- The technique does not consider variability (see section 1.6.1). Where variations occur, which is often the case during the construction phase, it requires re-design of the chart as a whole. This makes the updating process using L.O.B difficult, time consuming, and in many cases confusing.

2.5. C.P.M And PERT :

Three decades have now passed since the introduction of the original network models (C.P.M and PERT). In that period, their names have became common words and their function is well established in use. Probably thousands of books and articles have been written on their concept and analysis. They can not all be reviewed here and this chapter considers only the most important.

A network, essentially can be defined as a flow chart of workpackages or activities(see sections 1.7.1, 1.7.8) designed to show the precedence relationships between them. A single activity initiates and completes the network, between them. Activities may take sequences in parallel or in series with other sequences. The inclusion of an activity in a sequence is determined by technical or resourcing dependencies.

2.5.1. Historical Background :

The development of the network techniques started in Britain, and in America and Europe in the late 1950s. In Britain, in 1956 the Operation Research section of the Central Electricity Board investigated problems concerned with the overhaul of generating plants. This overhaul operation was of considerable complexity and increasing importance, since at that time, a new high-performance plant was being brought into service.

By 1957, the O.R.section had developed a technique called "longest irreducible sequence of events". In 1958 they carried out an experimental overhaul at a power station using the technique which reduced the overhaul time to 42% of the previous average time for the same work. Continuing to work upon this line the overhaul time was further reduced, and in 1960, the average time had fallen to 32% of the original average time. The term "longest irreducible sequence of events" was soon replaced by "major sequence" and referred to the activities which control the total completion time of the work.

In 1958, Roy in France was working independently on the same concept, and in 1960 he perfected a working technique, he called a "method of potentials". At the same time, in 1957, the Special Project Office of the U.S.Navy set up a team of specialists to investigate the problem of planning and controlling complex research and development works. The purpose was to produce a management control system suitable for use on the Fleet Ballistic Missile (POLARIS) program. The main problem of this program is the co-ordination of the activities of thousands of subcontractors who were using estimates of delivery time which were highly unreliable. This investigation was known as the Program Evaluation Research Task, which gave rise to the code name, PERT.

By February 1958, Dr.C.E.Clark presented the early concept of the activity-on-arrow diagram(AOA), doubtless drawn from the study of graphics. Within the team, the early work of Dr.Clark was rapidly improved, and by July 1958 the first version of PERT became ready for use. By October 1958, it was decided to apply PERT to the Fleet Ballistic Missile program, where it was credited with saving two years in the development of the polaris missiles [88]. Similar development work was taking place elsewhere at the same time. For example, the U.S. air force developed their own version of PERT, called "Program Evaluation Procedures" (PEP).

Between 1956 and 1957, M.Walker at Du.Pont company and J.E.Kelley at the Remington Rand Univac division of the Sperry Rand corporation joined together as a team to work on the problem of scheduling and controlling the time and cost of construction, maintainance, and shut down of the chemical process plants. They adopted rational, disciplined, and simple procedures. At the beginning, this became known as the "Walker and Kelley method", and later the critical path method (C.P.M.) [2,6,38,118]. Other independent research was undertaken in 1958 at Stanford University under the sponsorship of the U.S.Navy Bureau of Yards and Docks. The aim was to improve the process of planning and controlling construction projects. This research introduced the concept of precedence diagrams.

Before this research, the work at Stanford had been directed toward the application of industrial engineering techniques to construction. One of these techniques is the use of the flow diagram in which job operations are represented by circles, and lines are used to connect the circles and symbols which are representing other type of operations. When the 1958 research started, it recognized the need for a project model, and having no knowledge of C.E.Clark's work on the arrow diagram (AOA) they used what is called a circle-and-connecting line diagram in which the network nodes represent activities rather than events.

Further work at Stanford resulted in two of the earliest computer programs using the circle and connecting line diagram. Later authors referred to this type of network presentation as the activity-on-node diagram(AON). Despite the separate origins of C.P.M. and PERT, their structure and concepts are very similar. Both use the same procedures and symbols for building and presenting the network plan. Both require time estimates for each activity in a project, which are used in very routine-type calculations to determine project duration and scheduling data for each activity.

The calculations determine which activities must be kept on schedule if the calculated project duration is to be realized (critical activities), and which activities have extra time (float time in C.P.M. and slack time in PERT) available for their performance. The main difference between C.P.M. and PERT lies in their assumptions regarding the nature of the time duration of each activity and the project as a whole. This difference is due to the fact that each of these techniques was evolved and developed in a quite different environment.

C.P.M. was developed under circumstances which were considered stable at that time. The calculations for this technique require only a single time estimate of each activity's duration. It considers the value of this parameter as a constant which can be predicted with certainty.

PERT, on the other hand, was developed to control a program involving considerable research and design works. The time and cost of this type of work are influenced by many variables whose effects can not be predicted with certainty. Therefore, PERT was designed to accommodate the variability of the time duration of each activity and the duration of the program as a whole. The calculations of PERT involves a weighting of optimistic, pessimistic, and most likely estimates of the duration of each activity to obtain a single expected duration. The resultant single estimates are used to work out the project duration, in the same fashion as C.P.M. calculations. In addition to this, the calculations produce statistical output which allows prediction of the probability of achieving the project within the defined duration, or the achievement of any other intermediate project event, by a specific date.

For a full account of PERT assumptions and analysis, the reader can refer to a paper published by Malcolm et al [88], who are the originators of this technique.

2.5.2. Advantages Of C.P.M. And PERT :

The main advantages of the network model in general and C.P.M. and PERT in particular are :

1-It utilizes the planner's knowledge, experience, and instinct in a logical way first to plan and then to schedule [105].

2-It is an excellent model for representing a project's activities and their interrelationships.

The systematic procedures for drawing the network plan require a level of breakdown such that each activity must be completed before the following one commences. In those cases where an an activity can start when another is partially complete, the earlier one must be broken down further.

This requirement assists the planner in keeping track of all relationships and helps him to avoid the omission of any element necessary for work completion. It forces him to develop a more detailed plan, conveying his thinking more completely to the people who are intended to use it [2,6,12,54,61,82,105].

3-The network diagram is an effective tool for communication. Since it displays the interrelationships between the project's activities, managers of various parts of the project will be able to perceive very quickly how their portion affects, or is affected by, other parts of the project [82,103,139,140].

4-The most important property of the network technique is the concept of management by exception.

Network calculations define a relatively small sub-network of activities in a project which are critical to its completion. Since critical activities usually make up 10-15% of a project [2], they can receive management attention that is necessary on less important activities. Hence, management will be able to concentrate on the bottlenecks and trouble spots in a project rather than spreading their attention to all project activities.

Management by exception is very important, especially on a large and complex project [6,12,54,140].

5-It is a good model for forecasting, testing alternative strategies for executing the work, updating, and taking corrective action.

At the execution phase, as it is known, when the actual performance lags behind that forecast, the effects of this variation may range from a matter of no importance to one that is vital. The network plan when updated frequently provides adequate indications of the effects and consequences of schedule slippage on project performance. It is a reasonable model for updating and control [2,6,12,54,82,105,139,140].

2.5.3. Criticism Of C.P.M. And PERT :

Following their introduction in the late 1950s, C.P.M. and PERT received enthusiastic support in the technical magazines and trade publications, and their applications quickly spread to a variety of uses in many industries.

Apparently, the idea of the network model and its analysis was oversold to the top management in the construction industry who expected too much of the technique and overlooked its limitations. In practice, the performance of both C.P.M. and PERT did not live up to expectation, and the reality showed that each of them has its own shortcomings and deficiences.

During the last three decades, and throughout their applications, both have received much criticism regarding their structure and analysis. The following sections list the main criticism and discuss briefly the most important deficiences of both techniques. They are:

1- The presentation of the network and the output of its analysis involves a communication problem.

   Unlike the Bar Chart, C.P.M/PERT requires a certain degree of knowledge and computer support for its analysis. With some training, a small network prepared for a small project or made up of macro-activities of a large project, is relatively easy to read and use.

   While, a large detailed network prepared for a complex project, with the tabulation of activity times and floats is generally unintelligible, especially to those involved in the execution of the work.

   This is the main reason for using a linked Bart Chart to present the output of the network analysis to the people who are intended to use the plan [2,6,12,111,133,140].

2- C.P.M/PERT were not developed to satisfy the needs of construction planning and control, and were not intended to solve the problem of site control. It is a time-oriented technique, created in a military environment, where the main emphasis is usually put on the time completion of the work.

   While in the construction industry, the main aim of the contractor (see section 1.3.2) is to minimize his total cost rather than minimizing the calendar duration of the project as a whole [9,12,18,38,61,111].

3-The C.P.M/PERT model does not consider directly and explicitly the availability of resources. Its structure lacks the necessary logic and notation to represent the availability , the flow, and the interaction between the required resources.

   This deficiency has created the following problems:

a)-The structure of the model and its analysis treat project activities as independent entities in terms of timing and resourcing. In many cases, and especially on construction projects, two or more activities appear on separate parallel lines in the network plan which must be performed at the same time. In reality, they may have to share the same workspace, and perhaps the same resources and supervision. By ignoring these interdependencies between activities, the analysis underestimates the completion time of the project which in turn makes the plan and schedule unreliable for project control [12,61,105, 111, 139,140].

b)- The model ignores resource constraints, it assumes that the required resources can be made available when they are needed. Because of this assumption, very often if not always, the network study of the project produces a plan and schedule which is physically unfeasible and of no use for site control.

The schedule results in a resource profile with big fluctuations, which means that the manpower can be hired and fired at any time, and equipment can be brought in and out of the project at any point in time throughout the construction phase.

This outcome of the network analysis not only ignores the resource constraints, but also neglects the need for a continuity of work for each resource to avoid idle time and the cost of those resource movements in and out of the project that are necessary for economic operation and the satisfying of contract conditions.

Faced with this situation, the planner has to restructure the plan and rerun the analysis several times until he obtains a workable solution, which can satisfy the resource constraints and meet the project targets [2,6,7,38,131,133,139,140].

c)-To satisfy the constraints on the availability of resources, and to provide a continuity of work for all resources, practitioners attempt to solve this problem using inappropriate techniques that were incapable of providing valid solutions. This they do by mixing the requirement of continuous flow of each resource with the technological logic which defines the relationships between the project's activities (this will be more clear in chapter three).

This way of going about the problem, in many cases, satisfies only part of the requirement, and the outcome of the analysis usually turns out to be a temporary solution.

It results in a plan with a rigid structure vulnerable even to minor changes. When any change occurs on site, which is normal, it causes restructuring of the plan as a whole and the process repeats again and again.

Another problem of the same nature faces the planner very often in practice. In many instances, he has to satisfy the requirement of moving different resources between on-going projects. This is to provide a continuity of work, especially for skilled labour and equipment, to avoid idle times and the cost and difficulties of hiring and firing technical staff. He does that by linking the plans of those on-going projects and imposing a false logic at the linking points which results in the same consequences mentioned above.

d)-The forecast floats and critical path produced by C.P.M/PERT analysis are false. They do not represent those in reality, because the calculation is based on incomplete relationships between the project's activities.

This is one of the reasons why the network plan and schedule need updating all the time during the execution phase.

4-The physical meaning of float is not clear and incomplete.

In general, the execution of any construction activity requires the following main resources: Labour, material, machines, money, supervision, and workspace.

Site management is normally able to make these resources except workspace. If the workspace is occupied by preceding activities nothing can be done about it (other than in exceptional cases where it may be possible to introduce alternate technology), and in this case the availability of a workspace can be looked at as a centre of criticality.

Including the availability of workspace together with the availability of other resources in the network structure and analysis gives the float clear physical meaning, and its value becomes complete and reliable.

5-The concept of various types of float is confusing, misleading, and very difficult to comprehend and use.

Three types of float are produced and listed in the schedule of the network analysis, namely : total, free, and independent.

Total float is the spare time on an activity. It is shared by a set of activities on the same path. If it is partially or totally consumed, it will affect the float on both previous and subsequent jobs on the same chain.

Free float is the spare time on an activity, provided that immediate preceding activities have been carried out on the schedule, it will not affect the float of any subsequent activities.

Independent float is the spare time on an activity, if it is consumed, it will not affect either previous or subsequent activities.

Activities with total float do not necessarily have free or independent float, but those which have independent float automatically have free float.

Unfortunately very few people, especially at the supervisory level, appreciate the significance of the various types of float. For the majority of people on site the word float in the schedule means spare time on the activity in question [61,101].

In practice, total float is the most difficult type of spare time to use, even for well trained staff. At the execution phase, when the site management decides to move any activity between its earliest start and latest finish, this action will reduce the float on the subsequent activities on the same chain, and in extreme cases, it will change the critical path and the schedule of the project.

In a small network with simple links between activities, it is relatively easy to spot the affected activities to take the necessary precautions for the remainder of the work, but this task is almost impossible in a large complicated network.

In this case, the schedule has to be updated by re-running the analysis.

Because of the dynamic nature of site operations, the updating process needs to be done very frequently. Each updating may produce a new critical path and schedule which may confuse the people executing the work. As a result, in many cases, people using the plan lose their faith and confidence in it, they put it aside and resort to their experience, intuition, and common sense to run their work and manage the resources under their control.

6-The C.P.M/PERT network has a deterministic structure which does not allow for conditional activities.

In reality, in some cases, the subsoil conditions can not be predicted with certainty (e.g. the level of the hard soil, the level of subsoil water..etc). Each condition requires different amounts of work and different types and levels of resources. Including two or more conditional activities in the structure of the network, sometimes, is essential for obtaining a reliable schedule and realistic forecast of completion time.

7-C.P.M/PERT produces hard deterministic information.

C.P.M relies on a one point estimate for activity duration and ignores the uncertainty affecting project activities (see section 1.6).

PERT, on the other hand, considers the uncertainty factors by relying on three point estimates. Unfortunately, the PERT calculation converts three estimates into expected duration and produces the same type of information produced by C.P.M., but includes some statistical statement regarding the completion time.

In reality, since managers operate in a changing environment, they will have little confidence in using these deterministic statements as a basis for action.

8-Problems with PERT's assumptions and its approximate solution.

PERT was not popular in the construction industry, because the data required were and are still considered excessive and difficult to obtain.

In practice, PERT is mainly used for managing research and development projects [139].

Since PERT's estimate is included in the proposed model, it is necessary, here, to introduce the idea with more detail on its faulty assumption and the solutions proposed in the literature.

PERT assumes that the probable duration of an activity is Beta- distributed. It uses three point estimates for activity duration, namely: optimistic(a), most-likely(m), and pessimistic(b).

The values of the mean and standard deviation of the Beta distribution are assumed to be equal to (a+4m+b)/6 and (b-a)/6 respectively, and the variance of a project's expected duration is equal to the sum of the variances of the activities on the critical path.

The theoritical problems of these assumptions have been studied thoroughly by MacCrimmon and Ryavec [86]. They defined four sources of error:

a)-error introduced by assuming a Beta-distribution for activity time duration.

b)- error resulting from the inexactness of estimating a, m, and b.

c)-error introduced by the approximate calculations of mean and standard deviation values.

d)-A very serious error resulted from ignoring the effects of several paths converging on one event in the network, and relying on one path in calculating the expected project time and its variance. They called this error the "merge event bias" [86].

They proved that the PERT-calculated project's time is always biased optimistically, and in extreme cases the actual time of the project can be 50% greater than that forecasted by PERT-calculation.

Many authors have justified the assumption of the Beta-distribution. Their arguments can be summarized as follows :

The estimates of the time duration of an activity are mainly subjective, because the actual values and their probable occurances are unknown, and can not be known precisely, for a variety of reasons (see sections 1.3.3, 1.3.4, and 1.3.6). So, the selection of any specific distribution is a subjective matter, because it relies on the experience and the personal judgement of the estimator himself.

The adoption of the Beta-distribution is a good choice, because of the flexibility of this distribution in fitting any skewed sample [27,31,139].

Other authors, e.g. Kamburowski [69], and Van slyke [132] suggested the use of other distributions such as : Uniform, Triangular, bounded Normal, Gamma...etc. in addition to the Beta-distribution.

In regard to errors c and d above, much research has been done to provide a proper solution. The efforts in this area of research have taken two different routes : the analytical and the simulation approach.

The analytical approach produced plenty of complicated mathematical algorithms, some of them aimed at reducing the error, others at finding an exact solution.

In practice, none of these algorithms received any welcome, mainly because of their complexity, limited use in a small network, and the time and cost of their calculation. The features of each of these algorithms will not be introduced here, because of the limited space. For more detail and clarification, the interested reader can refer to the following major contributors to the subject:

charnes, Cooper, and Thompson [26], Bildson and Gillespie [17], Britney [19], Clingen [28], Dodin and Elmaghraby [42], Donaldson [43], Elmaghraby [46,47], Farnum and Stanton [49], Fulkerson [55], Grubbs [56], Healy [62], Kleindorfer [71], Lindsey-II [78], Lukaszewiez [83], Martin [89], Ringer [126], Anklesaria and Drezner [5], and Robillard and Trahan [128].

In 1963, R.M.Van Slyke [132], led the way in the use of simulation techniques for network analysis. He argued that in a network any of the paths can be critical, this depends on the particular realization of the random activity durations that actually occur. By using simulation, and following C.P.M. rules, for calculating the completion time, each iteration will produce a different critical path.

In this case, it makes sense to work out the criticality index for each activity. This is the probability of an activity being on the critical path. This idea (i.e. criticality index) revolutionized network analysis. It gave considerable thrust to the development of more advanced network techniques such as: GERT and VERT.

In his work, Van Slyke [132], conducted an experiment on several network with different configurations. He used a primitive Monte-Carlo method of simulation to work out the completion time for each of these networks, using different types of distribution for activity duration. He compared the outcome of the simulation experiment with those obtained using PERT calculations for same networks. He summarized the advantages of using Monte-Carlo in the network analysis as follows:

- Unlike PERT, Monte-Carlo considers and handles the correlation between activities.
- It considers the shape of the distribution of activity durations which gives more accurate results, While PERT depends only on the mean and the standard deviation of the distribution.
- It has flexibility in that any distribution can be used to represent activity durations, such as: Beta, Normal, Triangular, Uniform, or Discrete in any sort of mix. This allows the user to try different distributions and observe the effects.
- It produces unbiased estimates for the mean completion time.
- It gives more accurate estimates for the probability of meeting any specific scheduled dates.

  Despite these advantages, the main problem of the simulation solution is the lengthy time and high cost of its calculation.

  At that time the calculation speed of the computing facility was relatively very slow and the computing cost can not be justified for practical applications.

Hybrid Models:

Several extensions to the original network model were developed. These extensions are based on procedures which are borrowed from other Operations Research techniques and added to the original network model as a complement to its analysis and presentation. They did not change the structure or the rules controlling the network analysis. Their aim is to eliminate part of the deficiences of the original model and to provide wider application.

These added features include ideas such as:

Cost Control, Bar Chart, L.O.B., Resource Allocation, Time-Cost Trade Off, and Simulation. A discussion of each of these extended models is presented in the following sections.

2.6. PERT/Cost :

The first extension to PERT followed soon after its introduction to answer the criticism that its time-only consideration was not enough for project control. The PERT/Cost model was developed by the U.S.Navy in 1961 [65]. It was an attempt to include cost accounting in the framework of the original model [41].

This idea appeared reasonable. Instead of accumulating costs on a functional or departmental basis, the model identifies them by activities, so managers may more realistically appraise past and projected costs of a project, and identify the sources of excess costs. Since the way of modelling costs in PERT/Cost system does not match that of the accounting system, an efficient application of the model entails a dramatic change in the practice and the organizational structure of the enterprise who wants to use it.

In reality, and as is known, the construction industry is too used to its traditional methods. It was and is still reluctant to any rapid and dramatic change. So, when companies tried using PERT/Cost, they did not abandon their cost-accounting system, they ended-up using two systems. Obviously, dual cost-systems are not only costly, but more bothersome than beneficial.

For this reason, nowadays, it is very hard to hear about any practical application of PERT/Cost, except in a historical review [140].

2.7. C.P.M/PERT-Bar Chart:

The obvious and simple extension to C.P.M/PERT is to present its output in a form of a Bar Chart. A more elaborate extension is to include the interrelationships between activities, and represent the float as well, by linking bars in the Gantt Chart using horizontal and vertical lines. This method of presentation is known as Linked Bar Chart.

In 1967, A.L.Iannone [64] introduced full detail of the features of this method, he called it MOST (Management Operation System Technique). MOST or Linked Bar Chart has the advantage of being simpler than the network presentation to read and interpret, but to keep its size reasonable, activities have to be kept at a high level of aggregation. This means that the method is only useful for small simple projects, and for presenting perhaps the pre-tender and master plans (see sections 1.8.1 and 1.8.2). In essence, the Linked Bar Chart method does not offer any tangible improvement to the original network model except simpler presentation.

2.8. PERT/L.O.B :

In 1967, Digman [39,40], introduced PERT/ L.O.B. technique and employed this combination for the management of the activities during the design and production phase of a new product in the manufacturing industry. This model employs a network similar to PERT's to show the interrelationships and times of the activities needed to produce one product, and uses the L.O.B. procedures to design the rate of production and balance the input resources.

PERT/L.O.B. extends the capability of the original network model by including repetitive activities to reflect the production of multiple items. The network calculations follow the normal PERT procedures, except that in PERT/L.O.B. repetitive activities have multiple contact points rather than a single point in the PERT system. The production chart of this model shows a schedule for the number of units to be produced. The idea of this technique was adopted in the construction industry and used for managing repetitive unit construction such as: housing, high-rise building, highways...etc.

The method appeared under different names:
The Vertical Production Method (VPM) [104], and the Linear Scheduling Method (LSM) [66]. PERT/L.O.B. overcomes some of the limitations of both PERT and L.O.B., but still has the technical and practical deficiencies of PERT's structure and analysis.

2.9. C.P.M/PERT And Time-Cost Trade Off Analysis:

Time-Cost Trade Off analysis seeks to produce an optimum solution in terms of time and cost for the project as a whole. The initial development of its model can be traced back to the early part of 1960s, when concurrently both C.P.M/Cost and PERT/Cost models were introduced.

In the network model, the analysis assumes that the method and the level of resources for the execution of each activity have been selected and that single or multiple time estimates for their durations have been defined. Actually each activity can be achieved using different methods and combination of resources. The combination which results in a minimum cost is usually decided by experienced people in the field, and can be defined using some Operations Research techniques such as CYCLONE (section 2.15). This combination of resources will achieve the activity within a specific time called normal duration.

In practice, there are several ways in which an activity can be expedited to reduce its duration, but usually these methods increase the activity cost. The point at which an activity duration can be reduced further is called the crash duration. Between normal and crash points, there are a number of possible time-cost solutions.

During network planning, using a normal time for each activity will result in a normal project schedule and normal direct cost, while using a crash time for each activity will result in a crash project time and all crash direct cost solution.

This all crash direct cost schedule is very uneconomical, because the majority of a project's activities never became critical and extra expenditure on these activities to crash their durations is a waste of resources. In the network analysis, there is a minimum-cost crash solution, where only critical activities are crashed to their minimum durations. Between the normal and the crash solutions, there are infinite resource combinations, each producing a different time-cost solution. They make up the time-cost curve for the project as a whole. Since the indirect cost increases in the opposite direction of the direct cost, the optimum time-cost solution will lie between the normal and crash points on the time-cost curve.

The main objective of the network/time-cost trade off procedure is to define this solution. The efforts expended in developing this procedure have produced two different models: Heuristic and analytical.

2.9.1. Heuristic Models :

The procedure for such models can be summarized as follows:

1-Construct the network.

2-Obtain alternative time-cost estimates for each activity.

3-Select the normal time and minimum cost alternative for each activity.

4-Calculate the length of the critical path and compare it with the target date.

5-If the length of the critical path exceeds the target date, select shorter time alternatives for one or more of the critical activities which have the smallest slope in their time-cost curve, between other critical activities, and repeat step (4).

6-If the completion time meets the target date, work out the total cost of the project schedule.

7-Select the next shortest time for any activity on the critical path with smallest time-cost slope, re-run the analysis, work out the total cost, and compare it with that of the previous run.

8-If the total cost of the current schedule is less than that for the previous schedule, repeat step (7). If not, the previous schedule represents the minimum cost schedule.

For more details, Ahuja [2], Antill and Woodhead [6], Elmaghraby [47], Fondahl [54], wiest and Levy [139] introduced full accounts for this model.

Although, the model is mathematically sound, and the idea is very attractive especially to the management whose goal is to obtain a schedule with minimum cost, the procedure has never been adopted for construction planning for the following reasons:

- The model assumes unlimited availability of resources, so the output schedule is not feasible in terms of resourcing [54,139].
- The time-cost relationships of each activity are difficult to obtain in many cases, either these data are not available or because estimates are too bothersome and very expensive to compile.
- Even if the required data are made available the cost of the calculation is too high to be easily justified.

2.9.2. Analytical Model :

The heuristic procedure does not provide an optimum solution because:

- It assumes a continuous linear relationships between the time and cost of each activity. In reality, this relationship is not known, it may be neither continuous nor linear.

- It ignores the possibility of reducing the direct cost further by using the independent float of non critical activities.

Time-cost trade off analysis has occupied the efforts of many researchers in the field. Several sophisticated mathematical algorithms have emerged to provide an exact answer to the problem.

In 1961 D.R.Fulkerson [55], applied the concept of linear programming to C.P.M-Cost to obtain an optimum schedule in terms of time and cost. Later, in 1962, Charnes and Cooper [25] improved Fulkerson's procedures. They assumed a linear relationship between an activity's normal and crash time in the time-cost curve.In 1965, W.L.Meyer and L.R.Shaffer [91], devised integer-programming to include any arbitrary time-cost curve. In 1967, W.Crowston and G.L.Thompson [34] integrated D.C.P.M. with the concept of integer programming to produce an optimum solution. At the same time, Bucher [21] applied dynamic programming techniques.

In 1979, T.J.Hindelang and J.F.Muth [63] developed an algorithm based on D.C.P.M and dynamic programming which improved Crowston's model [34] to include discrete time-cost relationships. In the early 1980s, S.Perera [112,113,114] used a chain Bar Chart with linear programming to get a minimum cost schedule.

The literature available on these models is extensive, Ahuja [2], Elmaghraby [47], and Moder and Philips [93] give full details regarding the structure and the analysis of such models. Despite these models providing an exact answer, in practice, they failed to be adopted as a management tool for scheduling and control. The main reasons for their failure are:

- They did not overcome the practical problems of the heuristic model (see section 2.9.1).
- They relied on mathematics very heavily which makes them difficult to understand and apply.

- They can handle only small networks, because the formulation of a real life network using these models results in a large number of variables and constraints which it is impossible to handle even with modern computers.

2.10. C.P.M/PERT Resource Allocation and Levelling :

As mentioned earlier, the network analysis on its own results in an unworkable schedule (see section 2.5.3.3), because it does not consider the availability and constraints of the required resources. Soon after the introduction of C.P.M/PERT, people working in this field realized the need for better procedures which can handle both precedence and limited resource constraints.

The efforts in this area of research produced two different models: analytical and heuristic. The structure and the analysis of both models can take one of the following forms:

- A resource allocation algorithm: where the procedure allocates the available resources to project activities in an attempt to find the shortest possible project schedule such that its resource demand profile does not exceed at any point the fixed resource limit.
- A resource levelling algorithm: where the procedure attempts to reduce the change in resource demand of the project schedule without exceeding the target date.

2.10.1. Analytical Model :

Many researchers have tried very hard to formulate the problem using mathematical methods to find an optimum solution. The main difficulty was that the limited resource scheduling and levelling of resources is a combinatorial problem, as the number of variables and possible solutions increase enormously as the project size increases. Some of the academics who tried this approach are:

1. H.Everett-II [48] who used linear programming procedures to formulate an objective function to minimize the project's time subject to resource constraints.
2. F.A.Karaa and N.Y.Nasr [70], applied the same idea for handling the resource allocation problem in multi-project scheduling situations.
3. R.Petrovic [115], developed a dynamic programming model for resource allocation problems.
4. L.Schrage [130], tried to solve the same problem using branch and bound enumeration methods to minimize project completion time under resource limit.
5. E.W.Davis and G.E.Heidron [37] improved L.Schrage's method to handle multiple resource constraints.
6. S.E.Elmaghraby [47], in addition to his contribution, gave a full description of these models and their analysis.

These models have suffered from the same problems as the analytical models of C.P.M/Time-Cost Trade Off analysis, no practical applications have been reported in the literature and none can be expected.

2.10.2. Heuristic Models :

Because of the daunting problem of formulating analytical models and their impractical solution, the majority of researchers and practitioners opted for the heuristic approach.

Since the early 1960s, extensive efforts have been devoted to the development of heuristic programs for solving this combinatorial problem. The earliest models reported in the literature are:

- Multi-Ship, Multi-Shop workload smoothing program (MS) which was developed in 1962 by Levy et al [76]. It was designed to smooth the manpower requirements in naval shipyards.
- Resource Allocation and Multi-Project Scheduling (RAMPS), was developed in 1963 by Lambourn [73] to solve the problem of allocating resources to several projects running at the same time.
- A Scheduling Program for Allocating Resources (SPAR-1), was developed by J.D.Wiest [38] in 1963.

RAMPS was a commercially available product (computerized), the other two were research tools [140], but eventually they became commercially viable models. In the following years, many other C.P.M-based scheduling programs were developed by both academics and industrial users. U.S Steel, General Electric, and several other firms designed their own software packages. Commercial models were developed by IBM and other companies dealing in computer software.

Today, one can find many highly sophisticated packages for scheduling projects with limited resources, designed to handle virtually unlimited numbers of activities and resource types. All these packages are based more or less on the same principles as the early models, perhaps with some modification of the heuristic rules.

The following two sections introduce brief ideas on the concepts of heuristic resource allocation and levelling algorithms.

2.10.2.1. Resource Levelling (heuristic model):

The process starts with drawing resource requirement histogram based on early start of the project schedule. Then the peak of resource demand is identified, and a limit value for resource level will be set one or more units below the peak. The schedule is considered period by period matching the intervals in the resource demand histogram. Starting at the first period and moving sequentially, resources will be allocated to activities in each period according to priority rules (critical activities first then those with greater float).

When the demand for resources exceeds the limit value, the start of an unscheduled activity will be delayed, and moved out of the peak period, but not later than its latest start. At the end of scheduling all project activities, a new flatter resource requirement histogram will emerge.

The process will be repeated again by identifying a new peak on the new resource requirement histogram, and setting a new limit value. The cycle then starts as explained above. The process stops when there is no possibility of improving the schedule without exceeding the project completion time which is defined at the start of the analysis.

2.10.2.2. Resource Allocation(heuristic model) :

The procedures define the early start resource requirement histogram, and the limit value of the availability of resources is defined by the user. Then the process considers the schedule day-by-day and proceeds as follows:

- At each day the available resources will be allocated to all activities which fall in the schedule on that day.
- When the resource demand exceeds availability the activity with greatest float will be delayed to the next day.
- When the start of any activity is delayed later than its latest start, the non-critical activities which are scheduled on previous days will be rescheduled, if possible, to free resources to the activity in question.

The process is repeated for every day in the schedule until all the activities are considered. In many cases, the new schedule exceeds the completion time defined in the original schedule.

If the new resource requirement histogram is subject to serious fluctuations, the resource leveling procedures can be applied to reduce the profile variability. The majority of today's software packages have both facilities (i.e. resource levelling and resource allocation). The technicality and sophistication of both algorithms are covered in detail in a number of good texts [2,6,8,47,54,82,105,108,139].

Among all hybrid models heuristic resource scheduling programs were and are still the most widely used techniques for resource scheduling in several fields and industries. The reason for their popularity can be referred partly to the fact that they are the only useable techniques available for solving part of resource scheduling problem, and largely to the successful marketing efforts of both software houses and researchers in the field.

Any practitioner with reasonable experience in using these programs for construction planning will readily agree that these models have the following deficiencies:

A)-The resource levelling model produces an unrealistic resource profile which does not match the reality. It may be suitable for a specific type of manufacturing industry.

In a construction project, the resource demand is usually very low in the early stages. It builds up gradually as the work progresses until it reaches its peak, it then declines until the end of the project. The change in demand happens in a discrete way, the labour force and machinery enter and leave the project in the form of gangs and crews. It is not as suggested by the model.

B)-Since both algorithms rely on using the available float for solving the problem, the analysis results in a very rigid schedule with almost all the activities critical.

At the execution phase, when any change occurs, a frequent event, the entire plan has to be restructured, because the float has already been consumed at the planning stage.

The solution offered by these methods not only defeats the object of having a flexible schedule, but also eliminates the best advantage of using the network analysis (management by exception) (see section 2.5.2.4).

C)-The model makes the following unrealistic assumptions:

1-It assumes that activity duration is fixed and invariable.

In reality the bulk of construction activities are performed by labour crews. Obviously the activity duration is a function of crew size.

Although, current programs can handle resources in a form of crew grouping, they do not consider the possibility of varying crew size at different stages of the project [111].

For example, suppose an activity is estimated to be performed in four days with a six-man crew. In practice it can eventually be performed in six days if only four workers are available (assuming no scale economies).

In this case, the model will delay the start of this activity until all the required six workers become available.

Varying the crew size at the construction phase is a normal practice.

Foremen make spot decisions when problems arise. They borrow and move some labour resource from one crew to another to expedite some activities and release more workspace for the following trades.

2- The model assumes that activities can be shifted freely between their earliest start and latest finish. The need for creating work continuity for each resource and the balancing of the whole production process are completely neglected.

Throughout its analysis, as long as the resource demand does not exceed the given upper limit, the process accepts uneven use of resources and proceeds to produce the final schedule.

Because of its assumptions and the nature of its analysis, the model is not able to tell which type of resource, at what quantity, where and when it is expected to be interrupted and stay idle. These are left to the user to discover from the final schedule at the end of the analysis.

Actually the process relies on a trial and error concept, and the required input (resource limit) can be provided only by guesswork, especially in the case of the resource levelling model.

D)-In many cases the model produces unfeasible, unworkable schedule, either because it exceeds the target date, or the required resources are imbalanced, or both.

In this case the planner has either to increase or decrease the level of some type of resource to obtain a balanced resource schedule or to change the method of working (i.e. use different technology and resources) to meet the target date.

With all options available to him, he will find himself at square one.

As he has to re-structure the plan and provide new estimates for all the affected activities.

Because of these deficiences, the plan and the schedule will have to be changed very often to cope even with the minor changes which happen very often on site.

In summary, since these models using the unrealistic schedule produced by the network model, as a base for their analysis, are not capable of producing a practical solution for site operations.

Finally, it should be noted, here, that all C.P.M/PERT "Time-Cost Trade off - Resource Allocation and Levelling " models (heuristic and Analytical) do not consider uncertainty in the time duration of each activity.

2.11. C.P.M/PERT-Monte-Carlo :

The Monte-Carlo method is a simulation process whereby many random values are selected from distributions and combined to determine properties of the problem under study [132]. In 1963, R.M.Van Slyke [132], explored the use of the Monte-Carlo method to find solutions to the PERT problem. Through his research, Van Slyke introduced the term "criticality index" for each activity. He defined this term as the probability that an activity would be on the critical path. He concluded that simulation offers the best solution in determining an unbiased estimate for project duration. It also eliminates the "merge event" problem in PERT network analysis. His work stimulated the idea of using simulation for the network analysis. Later many researchers included the simulation process in the development of the advanced network models.

In 1964, Berman [14] investigated the effect of uncertainty on the project schedule. He applied Monte-Carlo methods to PERT network analysis and considered the resource allocation. His conclusion was that uncertainty tends to direct resources towards the earliest part of the project. The major disadvantage of C.P.M/PERT simulation is the time required to simulate many iterations and the cost of calculation.

In 1971, J.M.Burt. Jr and M.B.Garman [20] developed an algorithm based on conditional sampling to reduce the size of the network. Hence reducing the calculation time and cost.

In 1976, K.C.Crandall [31,32,33] introduced a model called Probabilistic Network Evaluation Technique (PNET). It used the same idea as the Van Slyke model except that it considers only representative paths in the network to work out the completion time through simulation. The aim of this model is to reduce the size and cost of calculation.

In 1979, R.I.Carr [24] developed a model based again on PERT/Simulation called a Model for Uncertainty Determination (MUD). In this method the random variables affecting activity duration are classified into two categories :

- Independent of calendar date variables (INCAD) such as : productivity, sub-surface site conditions, the dependability of new subcontractors ...etc.
- Dependent upon calendar date variables (DECAD) such as weather.

  The MUD model instead of relying on a subjective estimate for activity duration, simulates the effects of these uncertain variables to obtain unbiased reliable time estimates for each activity and for the project as a whole.

The process of this model consists of two stages :

- First MUD runs the simulation to produce duration samples for each activity in the project under the effect of the (INCAD) random variables.
- At the second stage, sensitivity correction values are defined which relate the effect of the weather conditions and the daily progress of activities. MUD then simulates the progress of the project by correlating the sensitivity correction values and the actual weather data.

Samples of activity times are produced by repetition of the PERT calculations using the actual activity times produced by the first stage.

In 1984, Ahuja[3] developed a model based on PERT/Simulation to simulate a summary PERT network including the uncertainty of the availability of resources and cost parameters. The aim of this technique is to help the contractor in taking the decision to bid or not to bid.

In 1985, Ahuja and Nadakumar [4], used Carr's idea and developed a model called Project Duration Forecast (PRODUF) which was similar to the MUD model. All versions of C.P.M/PERT-Monte-Carlo models appear to be realistic, sophisticated and powerful, but they have not been applied in a real life situation for the following reasons:

1-All PERT/Simulation models are confined to produce a distribution of the expected completion time and a listing of the criticality index of project activities.

This information is essential to the decision making process but it leaves unanswered the question of project control. When are the activities likely to occur? How does management recognize and define a variation from the schedule?.

Theoritically, the model can produce a distribution for each schedule parameter of each activity in the project. One can imagine the nature and the amount of such an output, a distribution for each of the following elements : early start, early finish, late start, late finish, total float, free float, and independent float. This is for each activity.

This type of output is not only enough to confuse the management, but also to confuse a well trained analyst.

A solution for this problem is found in the model proposed in this work.

2-Many practitioners consider the required data excessive and largely unavailable. In addition to this the statistical output is too complex for management staff.

3- The capacity of computing hardware which was available to or within the reach of the industry before the 1980s is not enough to deal with the real size problem. Also the time and cost of the analysis can not normally be justified using these models.

Advanced Models:

Following the adoption of C.P.M. and PERT, and in the light of their deficiencies, questions were raised regarding the additional capabilities which might enhance the effectiveness of network analysis techniques. Research efforts have been made to develop methods able to model a complex system by compounding simple techniques [74].

2.12. Decision Box Network Technique :

In 1962, Eisner [45] developed a new method that could be used in the planning and scheduling of research programmes. It was called a Decision Box Network Technique. This method is a generalization of the PERT model, where the network has several finishing points, and events are represented by new symbols called the decision box. The network structure of this technique models alternative procedures to accomplish research tasks.

The analysis requires an estimate of the probability of adopting each alternative, and ranks the possible research outcomes in terms of the probability of their occurance. In this technique, Eisner used the standard PERT concepts for time estimating and scheduling, and imposed these estimates upon the network structure and analysis.

2.13. Decision C.P.M :

In 1964, Magee [87] published his decision tree analysis.
During the same period, Elmaghraby was working on the generalization of PERT and C.P.M. He developed an approach in which events occur probabilistically. He introduced extra logics to the network structure: AND, EXCLUSIVE-OR, and INCLUSIVE-OR. He also developed new algebra for graph reduction in the analysis of his generalized activity network. His approach appears to be applicable to the analysis of some practical situations in the construction industry (e.g. bidding decisions).

In 1967, Crowston and Thompson [34] introduced the concepts of Decision Critical Path Method (D.C.P.M.).

They described it as a method for considering the interrelationships between the planning and scheduling phases. They argued that resource constraints in construction (manpower, equipment, and materials) and weather conditions may lead to several decision alternatives.

In the D.C.P.M. model, at the planning phase, if there are a number of different methods of performing some of the jobs in the project, each method having different technological dependencies and different time and cost, all the different possibilities can be included in the project network. At the scheduling phase, the effect of the alternative methods on the total time and cost of the project can be studied, and the alternative that minimizes cost can be selected.

The D.C.P.M. model introduces decision nodes primarily on a deterministic basis. The time durations of project activities are assumed to be known with certainty. The D.C.P.M. network structure permits decision nodes to lead to several possible alternatives, but it does not allow any looping or representation of the logic of conditional activities. During the analysis, the realization of only one set of alternatives represented in the network and leading to the finishing activity completes the project.

Crowston and Thompson formulated D.C.P.M. as an integer-programming model to obtain an optimum solution to the Time-Cost Trade off problem.
They solved this problem by using heuristic rules and integer programming analysis. Their method of solution has some limitations and shortcomings regarding the number of variables and constraints.

Later, in 1979, Hindelang and Muth [63] developed an algorithm based on D.C.P.M and dynamic programming models. They claimed that their algorithm overcame the problem of the Crowston and Thompson method. As mentioned earlier, all the models which are based on mathematical techniques for their solutions did not receive any welcome in practice, because of the time and cost of their calculations and the limitations of being confined to small size problems. D.C.P.M. suffered from the same problems.

2.14. GERT :

GERT (Graphical Evaluation and Review Technique) was developed by Pritsker and Happ [119] in the mid 1960s.

As defined by its authors, GERT is a network-based simulation technique combining the diciplines of flow graph theory, PERT, D.C.P.M, moment generation function, queuing theory, and simulation.

The first version of this model lacked the necessary logic to cope with the intended application [36]. This stimulated the process of refinement and improvement of the technique and its analysis.

Between the mid 60s and mid 70s, several versions of the model have been developed, each opened new areas of applications. The last version called Q-GERT was completed by the original author in 1977 [120]. Dabbas [36] reviewed briefly the development stages of all versions.

The graphical presentation of GERT consists of arrows to represent activities, and nodes to direct the flow through the network.

Unlike the original model (C.P.M/PERT), GERT allows looping paths and probabilistic occurrences of activities and events in its structure. It also considers uncertainty in respect of all types of cost and reliability parameters in addition to time. The simplest version of the model employs eight types of node with four different input logics controlling the release of the node, and two output logics : one deterministic and the other probabilistic to channel the flow through the network.

Since the network structure allows for looping, the input logic of the node determines how many incoming activities (branches) must be completed before the node is realized. This may differ between the first and the successive release of the node. The deterministic output logic initiates all outgoing activities, while the probabilistic output logic initiates only one activity in accordance with its probability of occurrence.

GERT has been applied to a diversity of situations:
bidding, test programs, feasibility studies, flood control, missile count-down procedures, research projects..etc [120,140]. Several good texts [2,47,98,120, 121,122], and articles [100,110,135,140] contain detailed reviews of GERT development and its analysis.

GERT is a powerful, sophisticated technique. Unfortunately, the spread of its application was halted by the complexity and the huge amount of data required for its analysis. Although, its author [120] mentioned that GERT has been applied for managing some construction projects, there is a great doubt regarding its applicability in the construction environment. This is due to the following reasons :

1-The majority of its logics are redundant for modelling the dependencies of the construction activities.

For example: in a construction project when the design is finalized and the construction phase started, all activities have to be performed (activities are certain) and there is no need for re-design (looping). Part of GERT's logics may be suitable for project evaluation at the development stage.

2-GERT does consider resource constraints and balances them, but in a form applicable to the manufacturing process where resources are part of a cycle.

In a construction project cyclic operation represents part of the production processes at the micro-level of analysis (see sections 1.7.5, 1.7.6, 1.7.7, 1.7.8). Using GERT in this case results in unmanageable networks which are not only large and complex, but require too much data that can not be made available.

3-The logic and the structure of the technique is a programming language in its own right.

The number and the types of its logic together with the conditions of each, especially those of the last version (Q-GERT) are very difficult to understand, remember, and comprehend even by specialists.

2.15. CYCLONE :

The name CYCLONE is an acronym of the Cyclic Operation Network. It was developed by D.W.Halpin [15,36,58,79,80,81,134,141], in the early 1970s, and defined as a network-based simulation model for the analysis of construction operations. The formulation of this technique is directed towards the micro-analysis of the construction operation and its components (processes and work tasks) (see sections 1.7.5, 1.7.6, 1.7.7, and 1.7.8).

The aim is to study in detail the interrelationships between the different processes and work tasks, and the interdependencies between the resources. This is within a defined method of working and technology. The analysis of CYCLONE pinpoints the bottlenecks in this type of production system, balances the whole process, defines both the rate of production and the optimum crew size and composition of each of the resources, and finally produces an estimate for the time and cost of the operation. CYCLONE focuses attention on how an operation is achieved, and how the interaction between resources at the work task level leads to imbalances which affect productivity and unit cost.

The main objective is to replace the traditional methods of estimating time and cost which rely on experience and intuition. The concept of CYCLONE are mainly based on a process interaction simulation model. The structure of its network and analysis are completely different from those of the original network models (C.P.M/PERT). With CYCLONE the network consists of a set of cycles. Each cycle represents the flow of a specific entity (resource or end product) through the production system. The relationships between these cycles are defined by the technological logic of the production process. The network can have one or several starting points used for initiating the simulation experiment, and one or several finishing points used to record the number of production units produced.

Unlike C.P.M/PERT, CYCLONE analysis does not produce schedules, it treats time as duration only. In other words, the calculation records only the length of time during which each entity stayed idle during the simulation run. It does not record the starting and the finishing time of each process. There is therefore, no consideration of the greater or equal to relationships between the processes which produces the schedule and defines the critical path in C.P.M. calculations.

The CYCLONE network consists of a set of nodes and arcs representing the flow of entities (resources or end product) from their idle states to their active states in the system. The graphical presentation of the network uses three different symbols: square node, circle node, and arc.

Five types of nodes are used in CYCLONE to represent the dependencies and the relationships between the production processes : NORMAL, COMBINATION, QUEUE, ACCUMULATOR, and FUNCTION nodes. Each has a specific logic and function in the system. The technicality of the structure and logic of these nodes will be introduced in chapter four. CYCLONE uses Monte-Carlo methods of simulation to chart the progress in the modelled system. It can handle the time duration of each process in the form of any standard distribution.

At the end of simulation, the analysis produces time estimates for completing the operation as a whole with its unit cost of production, and the percentage of time each resource used is likely to be idle.

The development of CYCLONE was motivated by the deficiences of the existing network models at that time [79], and mainly of the GERT methodology. The main shortcoming of the first version of GERT is that it allows only one queue to precede each process. This causes the requirement for a complex network to model the construction operations.

Halpin [59] introduced and defined the COMBINATION and QUEUE nodes to overcome this problem. By using both these nodes it becomes possible to represent the effect of delays in a simple formulation. That is multi-ingredient processes or work tasks can be constrained until all the ingredients (resources or end product) are available.

Also, Halpin [59] assigned another property to the QUEUE node, namely the logical routing mechanism. That is, entities delayed at the QUEUE nodes preceding various COMBINATION processes are routed to the first follower that is available. If two or more COMBINATION nodes are available at the same time, the intrinsic QUEUE mechanism routes the resource to the COMBINATION node with the lowest numerical label.

CYCLONE continues to develop. In 1973, Halpin directed a project called computerized construction management [85]. He utilized the basic concepts of CYCLONE and C.P.M.

Later, Kalk [68] worked on a system called an Interactive Simulation of construction operation using Graphical Technique (INSIGHT).

During the period 1974-1976, Knott and Woodhead [6,36,58,79] developed a system at the University of South Wales in Australia called the CYCLONE Time Lapse Analysis System which is an advanced version of the original model incorporating discrete event time analysis.

Later, L.S.Riggs [125] developed the original software of CYCLONE to include cost considerations and automatic sensitivity analysis. At the same time, Dabbas [36] integrated CYCLONE analysis with C.P.M. He used the model to produce estimates for the time and cost of the activities which have repetitive processes. These estimates are used in C.P.M network analysis to produce the project schedule and cost.

In 1983, Tavakoli [134] developed a standard CYCLONE network to study and analyse the repetitive operations in road construction.

Finally, in 1986, Bernold [15] developed a conceptual model to combine CYCLONE with a knowledge-based expert system. CYCLONE has been used in practice for studying specific types of works such as the haulage operation and earthmoving in road construction [79,134], formwork and cast-in-place operations in high-rise building projects [58]..etc.

There is only one text "Design of Construction and Process Operations", written by Halpin and Woodhead [58] containing a full account of the features of CYCLONE and its analysis.

In conclusion, the CYCLONE methodology is easy to understand and apply. It is a powerful technique and an excellent tool for modelling a complex system and for studying the behaviour of all production elements.

The most important feature of CYCLONE is that it considers directly and explicitly in its structure and analysis the availability of resources and their interdependencies. With CYCLONE, the manager has the facility to experiment on paper with different methods of working and different levels of resourcing. He can choose between the possible alternatives, the policy and the combination of resources which can result in an economical operation.

Despite these advantages, this thesis contends that the CYCLONE methodology in its current form has limited prospect for use in practice, for the following reasons:

1-The cyclic nature of its structure and analysis confines its capability to model only one or a limited number of operations which have, specifically, repetitive processes and which can be represented through a closed cycle network.

This feature, as shown in practice, is suitable for modelling the operations of the manufacturing section in the construction industry and some operations of linear projects such as :

-A concrete-mixing central plant.

-A pre-fabricated concrete element plant.

-Windows and doors workshop.

-Earthmoving operation in road construction.

-Placing concrete and using slip-form in high-rise building projects.

2-As indicated above, the analysis of this technique is not able to produce a schedule, mainly because of the cyclic nature of the network itself, and partly because of the detailed level of the analysis.

Inability to produce scheduling information defeats the object of planning, because it ignores all the requirements of project control. This makes the technique in its current form not suitable for construction planning and control.

Nevertheless, the major contribution of this technique is the introduction of the concepts of COMBINATION and QUEUE nodes which makes it possible to model more than one queue as precedent for a single activity. This idea is extensively used in this thesis and these concepts are used in the development of the proposed model.

2.16. VERT :

VERT (The Venture Evaluation and Review Technique) is a stochastic network-based simulation technique designed to model decisions under uncertainty [96]. This technique dates back to the early 1970s when it was developed by Moeller [94] and applied to assess the risks in major U.S.weapon system development projects [94,96].

Since that time, VERT has continued to be modified. Several versions of the technique emerged, each with added feature and capability to handle more complicated situations. The current version (VERT-4) was completed in the early 1980s. Its features and application are fully described by Lee, Moeller, and Digman [74]. As in GERT, VERT's structure incorporates probabilistic occurrences of events and activities, but unlike GERT, it does not allow looping paths in its network.

The stochastic nature of its structure allows the modelling of several possible routes for pursuing the work at each stage of research and venture projects. This also includes the probability of achieving a successful outcome for each route at each stage. At the analysis phase, in this technique, the inclusion of any route at any stage is determined by one or more successful routes in the previous stage.

The analysis evaluates each stage of each route in terms of their duration, cost, and performance, and produces information on the best route for achieving the venture as a whole. The VERT methodology, as introduced by its authors [95], is a computerized mathematically oriented network based simulation technique. The graphical presentation of its network uses an activity-on-arrow (AOA) diagram where arrows represent activities and nodes represent events, milestones, and decision points. VERT model deals with up to three types of uncertainty on each activity, namely: time, cost, and performance. The values of these parameters can be sampled independently from one of the following thirteen statistical distribution generators embedded within the structure of the VERT program :

1)-Uniform; 2)-Triangular; 3)-Normal; 4)-Lognormal; 5)-Gamma; 6)-Weiball; 7)-Erlang(Exponential); 8)-Chi-square; 9)-Beta; 10)-Poisson; 11)-Pascal (Geometric); 12)-Binomial; and 13)-Hypergeometric.

In addition to the possibility of using constant values and a histogram facility. VERT has a rich set of node descriptors which make it a very robust technique for modelling very complicated systems. It uses two types of nodes which either start, stop or channel the flow in the network. The most often used is the split-logic node. It has separate input and output logics according to the type of its function in the model. The second less frequently used type is the single-unit logic node.

There are four different logics available for split-logic nodes :

- -INITIAL (to start the network and initiate the flow, multiple starts may be used);
- -AND (requires all incoming arrows (immediate preceding activities) to be complete before transfering control to the output logic);
- -PARTIAL AND (needs at least one incoming arrow to be completed successfully before allowing the output to proceed through, it will await full completion of all active incoming arrows); and
- - OR (also needs at least one incoming arrow to be completed successfully so transfering control to the output logic without waiting for further incoming arrows).

There are six output logics that may be combined with any of the input logics to define the function of any split-logic node :

- -TERMINAL (used to define the end of the network, multiple end points may be used.);
- - ALL (initiates simultaneously the start of all arrows exiting a node);
- - MONTE-CARLO (allows only one exit arrow to be initiated on a basis of random choice performed by this logic and based on the probability of realizing the activity represented by each arrow, the probabilities assigned to all exiting arrows sum to unity.); and
- - FILTER 1,2,3 (allow the continuation of the flow if one of several conditions expressed by the user are met, such as the achievement of a set of targets of time, cost and performance in some combination, or if a certain number of preceding activities in

the network have been realized, or if a specific types of activity have been realized.).

For the single-unit logic nodes, there are four types of logic:

- COMPARE (allows the continuation only for the flow which carries the best combination of time , cost, and performance parameter and satisfies the conditions defined by the user.);
- PREFERRED (allows the continuation of the flow whose performance matches the user preference of conditions);
- QUEUE (routes the incoming flows according to priority diciplines defined by the user according to time, cost, and performance parameters.); and
- SORT (routes each flow to the appropriate outgoing route according to time, cost, and performance criteria.)

As in C.P.M/PERT the nodes in VERT are used to aggregate the accumulation of data and arrows are used to generate data and pass the accumulated data to the nodes. So arrows in VERT have a primary and a cumulative set of time, cost, and performance data, while nodes have only a cumulative set. In VERT, it is possible to link any node with any preceding node in terms of time, cost, and performance parameters using the mathematical relationships facility of the program.

For example, the relationship between the time and cost of an activity can be described by a formula. During the simulation the sampled value of time could through the formula determine the value of cost for each iteration of the activity. The cost value would be assigned to the node and used in later aggregations.

VERT is a powerful , sophisticated tool. It was noted by its authors [74,95] that it has been helpful to management in cases where there is a need for making decisions with incomplete or inadequate information about alternatives, such as : the assessment of risks involved in new ventures, the estimation of future capital investment, evaluating several possible options for developing a complex system ...etc.

At the same time the originators of VERT [74] stressed that "VERT's advantage is still primarily in the concept and the design and development stages of the project, although VERT can be applied to any decision involving chance". This thesis suggests that VERT is clearer than GERT in terms of modelling and presentation, and more robust in terms of logic and analysis.

Despite the versatility of VERT, the technique is not suitable for construction planning for the same reasons introduced in the case of GERT (see section 2.14). In addition, it does not consider the availability and the flow of the required resources, and the way of modelling cost through VERT is vague, unclear, and complicated. It may be very easy, even for the specialist, to make major mistakes in modelling cost. Such mistakes are very difficult to detect, and their consequences in many cases, will be vital in taking the final decisions.

Chapter Three

Problem Definition

And The Scope Of The Current Work

3.1. Introduction :

As seen in chapter two the original network model was developed in a military/industrial environment and designed for planning and controlling new ventures and complex projects. It was transplanted into the construction industry without consideration of the special nature and needs of the construction projects.

The reasons for the wide spread of adoption of C.P.M/PERT by the construction industry during the 1960s and early 1970s can be related to the following:

- The backing that C.P.M/PERT received from the Department Of Defence in the U.S.A who made the use of C.P.M/PERT as part of their condition of letting any project.
- The extensive marketing efforts by major computer manufacturers such as IBM as part of their hardware sales drive.
- The publicity that the technique has received from academics.

In reality the technique has recorded reasonable success at the aggregate level of planning. It suited the purpose of the top level of management whose main interest is the determination of targets and objectives.

At the detailed level of planning and control C.P.M/PERT has suffered from many set backs for the following reasons:

1-The network structure is rigid. It does not provide any room for flexibility in modelling.

2-The model lacks the necessary logics and notation for representing the availability and flow of resources. Therefore the resultant plan and schedule using C.P.M/PERT are based only on the technological dependencies between activities.

3- Since the technique does not consider resource constraints, the analysis in the majority of cases produces infeasible schedules which are of reduced value at the execution stage.

4- The inability of C.P.M/PERT to include the effects of uncertainty in the time duration of the activities. This produces an inflexible schedule unable to absorb even minor variations.

5- The form of the output of the C.P.M/PERT analysis is difficult to read, understand, and interpret properly by the people on site.

Also major part of the output information(different types of float) is confusing and in many cases is redundant.

These deficiences were recognized in the early 1960s, and much work has been done since to eliminate them.

The strength of the network approach trapped researchers in its framework, so the majority of people who worked in and are still working in the field of planning techniques could not depart from the basic concepts of the original network model.

During the 1960s, several hybrid models emerged (C.P.M/PERT; -Cost; -L.O.B; -Time-Cost Trade-Off; - Resource Allocation and Levelling) to enhance the capability of the original model, and to provide wider applications. These models did not survive simply because they failed to address the real problem. Their originators did not realize that their proposed methodology and solutions do not adapt easily to the construction environment.

From the available literature, it appears that the hybrid models, especially those which seek optimum solutions, were developed in an academic atmosphere isolated from reality. In this type of environment professors and research students may retreat to theory leaving the problems of construction management to the imagination, instead of spending time talking to the people who are on the firing lines dealing with the diversity of practical problems. This characterization may be unfair, but it is true that the majority of the hybrid models came from university environments.

By transplanting some features to the original model researchers made the model more complex and probably less comprehensible to the people on site who are intended to use it.

For these reasons, nowadays with the exception of C.P.M/PERT there is little comment about these hybrid techniques in application-oriented publications. More commonly resource allocation and levelling (heuristic models) are used in practice. At the same time (early 1960s), another direction of development took place aimed at modifying the structure of the original network model.

New advanced models such as D.C.P.M, GAN, GERT, and VERT came on the scene. As we have seen(chapter two), the adoption of these techniques for construction planning and control is not feasible as they were not intended for scheduling and control purposes and are too complex to comprehend, especially, by site management. CYCLONE, on the other hand, is an easy, powerful technique, but has a limited and specific area of application.

During the 1970s, the use of the original model in the construction industry saw a sharp decline for the following reasons:

1-The condition of the project's owner that the contractor should submit his plan in the form of C.P.M was relaxed.

2-Updating the network plan and schedule involve lengthy arithmatical calculations. This requires a computing facility not only in the head office, but also on site.

The computing facility at that time was not within the reach of many contractors.

3-Since in many cases the network plan was kept in the site office and rarely referred to, there was little justification for using the technique.

By the end of the 1970s major advances had been achieved in data processing and computer technology. These advances led to the production of very powerful and portable microcomputers suitable for field environments.

In the early 1980s the use of C.P.M/PERT for construction planning and control started to increase and spread, promoted by the computer manufacturers and software houses. Nowadays, there are many software packages based on C.P.M and PERT including resource allocation and levelling algorithms of different capabilities and sophistication. Also computer courses on the use of the technique become part of student education in the universities and colleges.

This means that the computing facility (hardware and software) and the necessary data processing expertise became available almost for every construction project. The computer eliminates the burden of the arithmetical efforts and the consequences of the possibility of errors in the manual calculation, but it does not solve the real practical problem. Indeed, many software houses, in marketing their network analysis packages , claim that their product is so powerful and so useful that their clients use it many times a week to manage their daily work on site. This claim is true, because the model is so poor that constant monitoring is required and the plan has to be continually changed.

In practice, this means that the site controller has to spend his time re-playing the role of planner recording what happened on the job and updating the network. Constant changes in the plan is a waste of time and confuses the foremen and people executing the work as almost every updating results in a new critical path and different critical activities which have to be assigned top priority. Ironically the foremen on site knew by intuition and experience which activities had to be expedited first to open more workfaces for the following trades. They make spot decisions when problems arise without reference to the network analysis or even to the bar chart.

On its own this represents a fundamental defect in the concept of construction planning as represented by the C.P.M/PERT technique. Nowadays, C.P.M/PERT with or without a resource allocation and levelling facility, and the bar chart are the only techniques used in construction planning and control. The hybrid models are still promoted by academics [2,6,47,82,105,139], but there is no sign in the application-oriented publications of these techniques being used in practice.

In this chapter the problem this work is intended to solve will be defined through discussing the difficulties facing the planner when he conducts detailed planning. A brief idea on the heuristic rules used by the site staff for managing their work to achieve predefined targets will be introduced. These two sections will outline the scope of this research and its target.

3.2. Difficulties Facing The Planner At The Construction Phase :

The special nature of the construction project as a unique undertaking affected by many forms of uncertainty (see sections 1.3, and 1.6) faces the planner with several problems and makes the task of planning very difficult to achieve successfully. At the construction phase, in addition to the many uncertainties which have to be taken into account in the plan, the planner is faced with the following serious problem: How to model management changing policy regarding the deployment of resources?.

It is well known, especially in a large contracting organization, that sites are remote and are not self-sufficient in terms of finance and resources. Resource allocation, in this case, is usually controlled by top management who move the available resources between on-going projects. Their resource deployment policy changes as the work on all projects progresses. The policy is usually dictated by the state of the construction and labour market, the financial position of the organization as a whole, and by the organization's overall targets.

During the execution of the construction phase, each day brings new information on the availability of resources, the reliability of new subcontractors and suppliers, the productivity of labour in the locality among other factors. A plan in general can be seen as a formal statement or expression of the judgement, decisions, and assumptions made by the decision maker (being a planner or a site manager) on how the work should proceed. Faced with uncertainty in the available information, and the lack of accurate, timely and systematic technical and production data, the planner can not simply abandon the decision making process. Because, as mentioned earlier, the required data on which he can base his decisions flows as the work progresses. It is generated when the action begins, and the action will not start if all decisions are postponed until all is clear and certain.

In this environment the planner is obliged to make forecasts of actions and performance based on his experience, intuition and judgement, and on the information available to him which is at best incomplete and uncertain. Generally any plan has three main dimensions: logic, time, and resources [82]. Throughout the process of planning and scheduling the planner makes decisions on each of these. His decisions, obviously, are constrained by the contract conditions and by the management policy in pursuing the work. These dimensions are interdependent linked by very complicated relationships. A decision on one can not be made in isolation because it automatically defines the features of the other two.

For example, a decision on a specific logic for sequencing the project activities indirectly identifies the interdependencies between the different resources, also it affects the duration of the project as a whole. Setting up a target date automatically restricts the number of possible sequencing logics for the activities and defines the level of each required resource.

3.2.1. The Logic Dimension :

This describes the way the construction phase will be carried out. It constitutes the backbone of the plan, because the length of time during which the plan can stay as a viable control tool during the construction phase depends on the quality of its logic. In any construction project there are two types of logic controlling the sequencing of its activities; an absolute logic, and a preferential logic [103].

3.2.1.1. An Absolute Logic :

This exists where there is only one way of sequencing the work.

For example : Slab construction follows the lower superstructure (i.e. columns or load bearing walls), foundations come after excavation ...etc. This type of logic remains unchanged throughout the construction phase.

3.2.1.2. Preferential logic :

In a construction project certain parts of the work can be sequenced in several ways, because the logic is not controlled by the technicality of the production process, it is based on experience, site conditions, contract conditions, and management preference.

For example: In a building project, internal partitions can be built before or after external walls. Finishing works can start at the top floor and move downwards or start at the bottom floor and move upwards.

Another area of preferential logic is the sequencing of the works on different parts of the project which have the same type of activities.

For example: The excavation works of the office block, the manufacturing hall, and the store building of an industrial project can be done in series or in parallel or a mixture of both. This may depend on any of the following factors:

- Contract conditions (the manufacturing hall should be handed over first).
- Site conditions (Space on site is insufficient to manoeuver resources).
- the availability of the required amount of resources which is usually uncertain.
- The management policy such as finishing all the excavation works simultaneously in order to release equipment to other projects.

The absolute logic is rigid, inflexible and can not be changed. It can be referred to as the logical skeleton of the project. While the preferential logic is flexible, it can be considered as the rest of the body of the project.

Preferential logic can remain reasonably unchanged at the summary and aggregated levels of planning (see section 1.8), but it can not stand firmly at the detailed level, because of the dynamic nature of the site environment. Indeed, preferential logic represents the core of troubles facing the planner. The problem of "what if" questions begins here when dealing with this type of logic. It is up to the planner to use his ingenuity and experience to design a plan which will remain viable for as long as possible during the execution phase.

Actually, the site manager and foremen usually manipulate this type of logic to cope with any problem as it arises in an ad-hoc way, and to provide a continuity of work for their resources and meet the project targets and objectives. Under these conditions departures from schedule quickly cumulate removing its monitoring value.

The dilemma at the detailed level of planning is that a pre-sequenced set of activities in parallel may have to be carried out in different sequences during the execution phase for different reasons:

The amount of resources that become available is less than that required because of unexpected delays in releasing these resources from other on-going projects. Alternatively, management may move some of the available resources to accelerate activities on other current projects. A set of activities planned to be carried out in series may require changing during construction, as for example, unexpectedly good conditions may prevail and more resources become available. This may persuade site management to conduct these activities in parallel. None of the available techniques in use can handle this situation, and in both cases, the plan needs restructuring to accommodate these changes.

3.2.2. Time And Resource Dimensions :

Actually, time and resource are two forms of the same dimension, because a decision on one defines the other precisely . The time dimension includes both the time duration of each individual activity and the overall duration of the project. The resource dimension involves the level of each type of resource required to complete the project.

Decisions on the methods and technology to be used together with a rough estimate of the amount of each type of resource are usually taken at the bidding stage. More accurate estimates of the level of resource together with forecasts of their availability for each major part of the project are made during the pre-construction planning stage (see sections 1.8.1, and 1.8.2). At the detailed level, especially for preparing construction and stage plan (see sections 1.8.3, and 1.8.4), detailed estimates for the time duration of each activity together with the level of resourcing are necessary for planning and controlling site operations.

As time is money, the planner can not ignore the cost implications of his decisions on time duration and the level of resourcing. He has to provide a plan and schedule which can meet the project target and result in an economical operation. Generally, two possible forms of objectives exist in a construction project:

1-The project duration is fixed and the aim is to find a schedule and resource level which can meet the target date with a minimum cost.

2-The level of resources is limited and the aim is to work out a schedule which results in minimum total duration and cost.

In all situations, the schedule has to provide a continuity of work for each trade to avoid the idle time which affects the total cost.

As shown earlier (see section 2.9), the total duration and cost of the project is a function of the time and cost of its activities with the main effect coming from the critical activities. The time and cost of each individual activity is dictated by the level of resources assigned to it, each level producing a different time and cost, and it is difficult to define the optimum level. The total time is also affected by the sequencing of project activities, different sequencing logic producing different total time and cost for the project as a whole.

Further, the time duration of each activity is affected by several forms of uncertainty (see section 1.6), and one can imagine how difficult it is to consider the uncertainty in estimating the time duration of each activity with a different level of resourcing.

From the above description one can easily see the complicated loop of the decision making process regarding the logic, time and resource dimensions. Making decisions on these dimensions at the same time taking the constraints and project target into consideration is difficult, and the difficulty increases with project size. In the absence of a tool which can handle this complicated situation and take all the variables into consideration, the planner is left with C.P.M and resource allocation and levelling algorithms which are based on inefficient trial and error method of analysis. The decision making process for planning and scheduling in C.P.M methodology follows a set of typical procedures:

1- Define the project activities.

2- Design the sequence of project activities and develop the network logic.

3- decide on the level of resourcing for each activity and estimate their time durations accordingly.

4- Find the critical path and work out the schedule of activities.

5- Based on the schedule develop resource demand histograms for each type of resource for the project.

6- Level the resource demand within the availability limits of resources.

7- Re-schedule activities to suit resource levelling (which usually does not guarantee a continuity of work for resources).

8- Repeat steps 2-7 until an acceptable solution is achieved.

These procedures are designed to help the planner to take his decisions on logic, time, and resources in series rather in parallel.

In reality, the planner finds it hard to isolate his decision on the sequencing logic from that on resourcing. In many cases, when there are two or more parts in the project having the same types of activity which technically can be carried out in parallel, the planner tends to sequence them in series if the forecast amount of resources is enough to carry out only one of them at a time.

For example : The excavation work in the manufacturing hall and the store building in an industrial project can be achieved in parallel, if the planner expects that the amount of excavation resources is enough to carry out one of them at a time, he will schedule these activities in series. This makes the problem worse, because if the amount of excavation resource is greater than forecast, these activities will be carried out in parallel, and the logic in the plan becomes invalid.

In practice, the planner assumes a normal level of resourcing for each activity to estimate their time durations. This level is based on experience, records of past similar jobs, and normal company practice.

In the majority of cases, he relies on a one point estimate for the time duration, chiefly because of the difficulties of obtaining reliable data regarding the variability of activity duration, and partly because there is no practical technique available to handle uncertainty and provide valid solution (see sections 2.9, 2.5.3.8, and 2.11).

After estimating the time duration for each activity the planner works out the schedule which usually fails to meet the target date or resource constraints at the first instance. Also the output schedule results in fluctuations in resource demand which means some type of resources have to stay idle during the execution phase.
These fluctuations are due to the assumption of a normal level of resourcing for all activities. This assumption ignores the reality, where similar types of activity are carried out by the same crew. Since the amount of work on these activities is not the same, the normal level of resourcing suggests that when the amount of work changes, the size of the crew has to be reduced and increased accordingly. This means hiring and firing part of the crew or the unneeded part has to stay idle until it is required.

By repeating steps 2-7 of C.P.M procedures, the planner may reach a schedule which meets the target date and satisfies resource constraints. But the requirement of continuity of work for resources is very rarely satisfied, and the planner has to review the resultant schedule and perhaps change some sequences in the plan to meet this requirement.

The problem with the trial and error method of C.P.M is that it does not direct the planner as to what to do to reach an acceptable solution in an efficient way. Some of the information necessary for the balancing of resources is not generated by C.P.M procedures. Another point is that, there is no facility to consider directly the cost of resources and other costs to evaluate the output schedule and solution. Through the C.P.M procedures, the planner at best gets a rigid schedule which is vulnerable to changes and has to be updated all the time.

In summary, the main problem is how to produce a flexible, workable, and reliable plan and schedule which can be used by people on site, and can stay viable for a long time during the execution phase. From what has been mentioned so far, there is a need for a methodology by which the planner can:

- Isolate decisions on sequencing logic from other decisions.
- Directly model the flow and availability of resources together with their cost and other costs, as well as the variability of the activity duration in order that he may evaluate the consequences of any decision in terms of time and cost.
- Experiment with different resource deployment policies to choose the best workable solution.

  In this case, reasons for following one policy will be clear for all personnel involved which in turn boosts confidence in the output plan and schedule.

  Also this feature is necessary for accommodating changes and answering "what if" questions.

3.3. Heuristic Concept Of The Construction Production Process :

We have seen that, deficiences in the C.P.M/PERT mean that they are rarely used at the detailed level for actual construction. Site management tends to rely upon heuristic methods using past experience and intuition. Since the available techniques fail to satisfy the site requirement, it is more realistic to look at the ways the site management thinks when planning ahead for controlling the work, and try to formulate a conceptual model for a realistic planning process.

This conceptual model is helpful in developing a methodology which can mirror the thinking of people on site. Site management uses common sense and rules of thumb in planning and controlling the work. The framework of these rules is called a heuristic concept. The heuristic concept in the execution of the construction phase is best described by the following paragraphs (they are quoted from an article written by G.S.Birrell in 1980 [18]) :

> " While carrying out a research project on another topic of management of construction, the writer spent considerable time examining planning for construction with more than a hundred project manager, site superintendent of general contractors, and foremen of subcontractors. It was found that their thoughts of how to carry out the construction process could be paraphrased along the following lines:
> Well, by looking at the drawings, I decide the sequence of the trades on a job and the route I want them to move through the job or round the site. Then I make the first work squad begin in a location, work space -whatever you want to call it- do their work and then move on to the next work space and do work there and so on through the whole job.
> As soon as I can, I'll bring in the second work squad in the first work space-maybe when the first work squad in the second space.
> Maybe I'll wait until the first squad is in the third work space before bringing in the second work squad to the first work space so that I have a "buffer space" between them. Then I move the second work squad in the same sequence as the first work squad. Then I add more and more squads through the same sequence.

Now, once I have these flows of squads moving through these work spaces I push them all to move-space to space at about the same time, I try to build a rhythm of work and movement which all of them follow.
It's like the old steam locomotive - the wheels are the work squads each progressing down the track and the piston and rods linking the wheels are my sequence of work squads and the work spaces- Me, the site super- I'm the steam governor, controlling the amount of "push" to move the pistons and rods (the plan) which make the wheels turn !. Then the rhythm moves them all through the job and I have to keep it as fast as possible but not too fast or the wheels will bump into each other or fall off.
You know, there is another thing, each of the work squads should be on the critical path -you can not afford to have one critical path- the job goes too slow !."

A close look at the above description of the heuristic concept suggests:

1- Site management perceives the production process as a queuing system and the job of planning is to design each production line and balance their production rate.

2- Site management decides the sequence of trades, the work spaces on the job, and then the work paths for all work crews through the work.

They think in terms of work crews and work space availability in designing their plan of work. This is compatible with the nature of the production process (see sections 1.3.4, and 1.3.5) and with the concepts of Project Breakdown Structure (P.B.S) which is introduced in section (1.7).

3-The work space plays a major role in deciding when to deploy resources and in setting up the pace of production. It also provides a buffer for the management to balance resources, avoid idleness, and to accommodate unforeseen conditions.

4- The level of resources builds up gradually to its peak and goes down towards the end of the construction phase in a discrete manner according to the number and size of the work crews. So the resource profile should not have fluctuations, nor should it be levelled and smoothed as the resource allocation and levelling algorithms attempt to produce.

5- Finally, for the site management the plan of work should be resource driven. The availability and the balance between different types of resources dictate the sequence of carrying out the activities (subject to the technological constraints) and define their criticality. While in C.P.M/PERT the opposite is true, the sequencing of project activities defines the level of resourcing and criticality, and the emphasis is on critical path and floats rather than on the balancing of resources.

3.4. The Scope Of This Research :

The idea for this work was inspired by the heuristic concept of managing the work on site (section 3.3). From this concept, it is clear that, construction planning at a detailed level is a matter of designing critical production lines for the available resources and balancing the rate of production on different lines to avoid idleness and provide efficiency.

In this sense, activities are oriented to the work of a resource crew in a specific location. When a crew finishes its work on one or more activities, another crew moves in to achieve another type of work. Throughout the construction phase, workspace plays a major role. It channels and holds the flow of resources through activities. In the author's opinion, the availability of a work space is often more critical for the progress than any other factor.

Resources such as materials, manpower, and machines can be made available any time at a price, but if a work space is occupied by a work crew, it can not be made available before the crew finishes its work in this location. Modelling the availability of work space forces the planner to conduct detailed planning. Using the work space concept at the summary level of planning misrepresent reality and other models should be used for this level of planning.

Detailed planning at the pre-bid stage is not economical for reasons mentioned earlier (section 1.8), and producing detailed construction plans for the project as a whole is not worth while, because of the dynamic changes of project environment and uncertainty of the available data. Since data become more certain as the time comes closer to the start of the work, detailed planning begins to increase in value. This is further enhanced when such plans cover a relatively short period of time.

Application of the original network models (C.P.M/PERT) had reasonable success in construction planning at an aggregate level. C.P.M/PERT, and in some cases bar charts will be good enough for producing pre-bid and pre-construction plans. For detailed planning, there is a need for a technique which can incorporate the heuristic concept and capture the thinking and experience of people on site. The structure, the logic, and the analysis of both CYCLONE and VERT attracted the author's attention. It seemed possible to modify part of the structure and logic of these techniques and combine them with the concept of critical path propounded by the original network models.

Based on the above mentioned theme, the main objectives of this research are:

1-To develop a network-based simulation technique with the following features and capabilities:

a)-Ability to model the heuristic concept of the construction process. Its user can produce a plan and schedule which mirrors the thinking of people on site.

b)-Ability to accommodate both absolute and preferential logic, with a flexible structure to remove the burden of making decisions on sequencing and resourcing at the same time.

The user can model the most feasible sequences without thinking of resources when taking decisions on the logic dimension, and can then experiment with different levels of resourcing to choose suitable solutions without the need for restructuring the plan itself.

c)-Ability to model the availability of work space and other resources. The user, after modelling the most feasible sequences, can impose the flow of the available resources on the plan structure and observe their interaction.

d)-Ability to accommodate both fixed and probabilistic time for activity duration.

e)-Incorporation of cost parameters in addition to time.

f)-The analysis has the ability to generate the following information:

- A range of starting times for each activity.
- A range of completion times for the project as a whole together with the probability of achieving the time and cost targets.
- A range of realization times of each stage of the project together with the probability of achieving their time and cost targets.
- Criticality index for each activity.
- Expected amount of free float available for each activity, eliminating the confusion of the total float.
- Expected amount of idle times for each type of resources at each location, and the total idle time and its cost for each type of resource.

With this type of information the planner can experiment, increase or decrease resource inputs until he reaches a satisfactory solution.

Any change on site can be accommodated and studied without the need for restructuring the plan itself.

2- To write a software package on a microcomputer to facilitate the modelling procedures and analysis of the proposed technique.

The next chapter introduces the development of the structure of the proposed model.

Chapter Four

Model Development

4.1. Introduction :

As noted in chapter three, the aim of the current work is to develop a network-based simulation technique which can capture the thinking of the planner (as a decision maker), and the people on site who are responsible for executing the work. The basic concept of the proposed model is based on a combination of parts of VERT and CYCLONE methodologies.

VERT network presentation uses activity-on-arrow diagrams, where nodes play the role of decision points in the model structure, and arrows represent activities.

CYCLONE, on the other hand, uses nodes to represent processes, work tasks and entity locations, and arcs to channel the flow of entities (resources or end products) from their idle states to their active states through the network.

The proposed model adopts the CYCLONE network configuration. In the structure of the proposed model. Some nodes and logics are transplanted directly from VERT and CYCLONE, and used as they were defined by their authors. The function of other nodes are modified and redefined to suit the modelling concept of the proposed technique.

This chapter introduces a description of the structure of the model with a justification of each of its nodes and logics. The data input, the analysis, and the output of the technique will be introduced in chapter five. In the current chapter, the development of the structure of the model will be introduced step by step. At each step, a description of the function of each node and logic used will be introduced as they were defined in the original model (VERT or CYCLONE) as well as any necessary explanation of incorporated modifications.

Throughout the discussion, the readers are assumed to be familiar with the VERT and CYCLONE methodologies, those who are not, are advised to refer to Lee et al [74], and Halpin and Woodhead [58] before reading the following chapters.
An outline of the procedures used in the model will be introduced at the end of chapter five, following discussion of the structure of the model and its analysis. To help the reader to conceive the function and the logic of each node used in the model, it is necessary to introduce a brief idea on the modelling rationale of the technique.

4.2. Modelling Rationale For The Proposed Technique :

The idea of the model is very simple. It treats the production process on site as a queuing system. In this system, each location in the physical structure of the project represents a stationary component of a certain queue of locations waiting to be served, and each type of resource represents a moving server flowing through a specific production line to serve a specific queue of locations. The end product of the activity of each type of resource changes the feature of the location and moves it from the current queue of locations to another queue to wait different type of services.

This queuing system has two basic elements that characterize its features. These elements have to be considered at the same time throughout the analysis. They are:

- The end product to be constructed at each stage.
- The resources required to achieve the construction work.

4.2.1. End Product :

When the planner and the estimator break down the project into its components (workpackages, functional element ..etc)(see section 1.7), they actually define the end product at each stage of construction.

For example, the breakdown of reinforced concrete columns construction into its elements (see figure 1-2) is actually a definition of the following products : Formwork, Steel fixed according to design, Concrete placed to formulate the body of the column ...etc. Each location in the physical structure of each part of the project can be considered as an entity. The position of this entity changes from an idle state where it is awaiting specific types of resources to arrive to conduct a specific activity, to an active state where it will be occupied by resources which have to achieve specific work at this location.

The active state of a location entity involves creating a new product which changes the feature of this location and transfers it from one specific queue of locations to another queue awaiting a different type of service.

For example: at the start of the construction work on an industrial project, the site locations of the manufacturing hall, the office building, and the store building form a queue of locations: A-1, A-2, A-3 which represents their idle state (figure 4-1). These locations await the excavation crew to arrive to conduct the necessary excavation works for foundation. When the excavation crew starts its work in any of these locations, the status of the location changes from an idle state at (A) (ready for excavation) to the active state (B), while the excavation is taking place.

At the end of the excavation work, the end product of excavation changes the feature of the location and moves it from queue (A) (waiting for excavation) (figure 4-1) to another queue (C-1, C-2, C-3) (ready for formwork and steel fixing). At this stage one can notice the following two points:

- The C.P.M/PERT network is able to represent only the active state of locations. It ignores an important element of the production process (idle states).

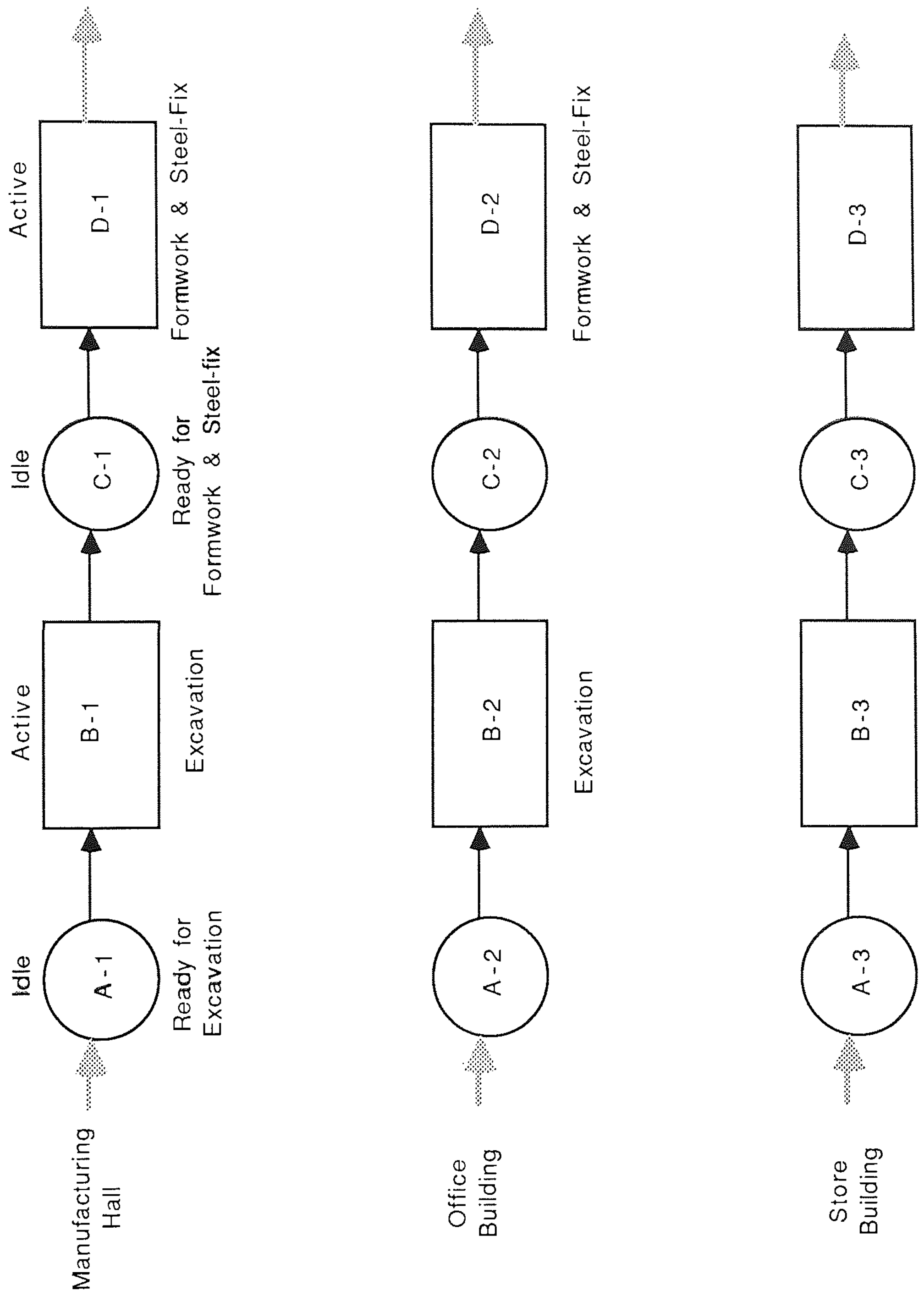

Manufacturing Hall
Idle
A-1
Ready for Excavation
Active
B-1
Excavation
Idle
C-1
Ready for Formwork & Steel-fix
Active
D-1
Formwork & Steel-Fix
Office Building
A-2
B-2
Excavation
C-2
D-2
Formwork & Steel-Fix
Store Building
A-3
B-3
C-3
D-3

Figure (4-1)

-The concept of the idle state of work location is the essential part of the heuristic concept of planning which is used by the site management (section 3.3). When an extra resources become available on site, the site manager first searches for an idle work location in order to assign work to these resources to keep them occupied and productive.

The idle state of work locations represents the sequencing logic between activities.

In figure (4-1), if the three chains (1, 2, 3) which represent the works in the manufacturing hall, the office building, and the store building are linked at their starts to one starting node, and at their ends to one end node, the figure will represent a network for the project as a whole. The idle state (C) represents the absolute logic (see section 3.2.1) between the excavation and formwork activities.

A close look at the network reveals that each type of activity (i.e. excavation, formwork) in all three parts of the project are modelled to be performed in parallel. This is the ultimate case of performing the project activities. It depends on the availability of resources, they can be achieved in parallel, in series or a mixture of both.

The sequence of achieving these activities will be left to the modelling of the flow of resources. In this way the logical structure of the network will remain viable as it relies only on the absolute logic.

4.2.2. Resources :

In the proposed queuing system each type of resource required flows through a specific production line to achieve its specialized work. The physical resources on site can be classified into two different categories : reusable and non-renewable resources, each having a different type of flow through the project work.

4.2.2.1. The Flow Of Reusable Resources :

This resource category includes labour, machinery and tools. The flow of each type of this category starts at a specific physical point in the project structure and flows through a predefined set of locations. This type of resource moves from an idle state where it awaits the availability of the next work location, to an active state where it conducts a specialized type of activity.

The resource leaves the project either when all its activities are completed or when part of its activities have to be conducted at a later point in the construction phase. The sample network in figure (4-1) is reproduced in figure (4-2) to show the flow of this resource category. In this figure (4-2), suppose that two excavation crews and one formwork crew can be made available for executing the work, and the priority is given first to the manufacturing hall, second to the office building, and finally to the store building.

The two excavation crews will be initiated at the start of the work. They move to their idle state (node EX-1), then each crew leaves the idle state to their active states (excavation activities B-1, and B-2). The first crew to finish its activity will flow back to the idle state (node EX-1), then directly move to the next available work location (excavation in store building B-3). On finishing this activity B-3, the crew will leave the site (node EX-3).

The other excavation crew, when it finishes its activity, returns to the idle state (node EX-1), then directly exits the site (node EX-2). The formwork crew will be initiated immediatly after the completion of the excavation activity (B-1). It moves to its first idle state (node FM-1) and then to the first available work location (activity D-1).

When activity (D-1) finishes, it moves to its second idle state (FM-2) where it awaits the availability of work location (C-2) to conduct activity (D-2),

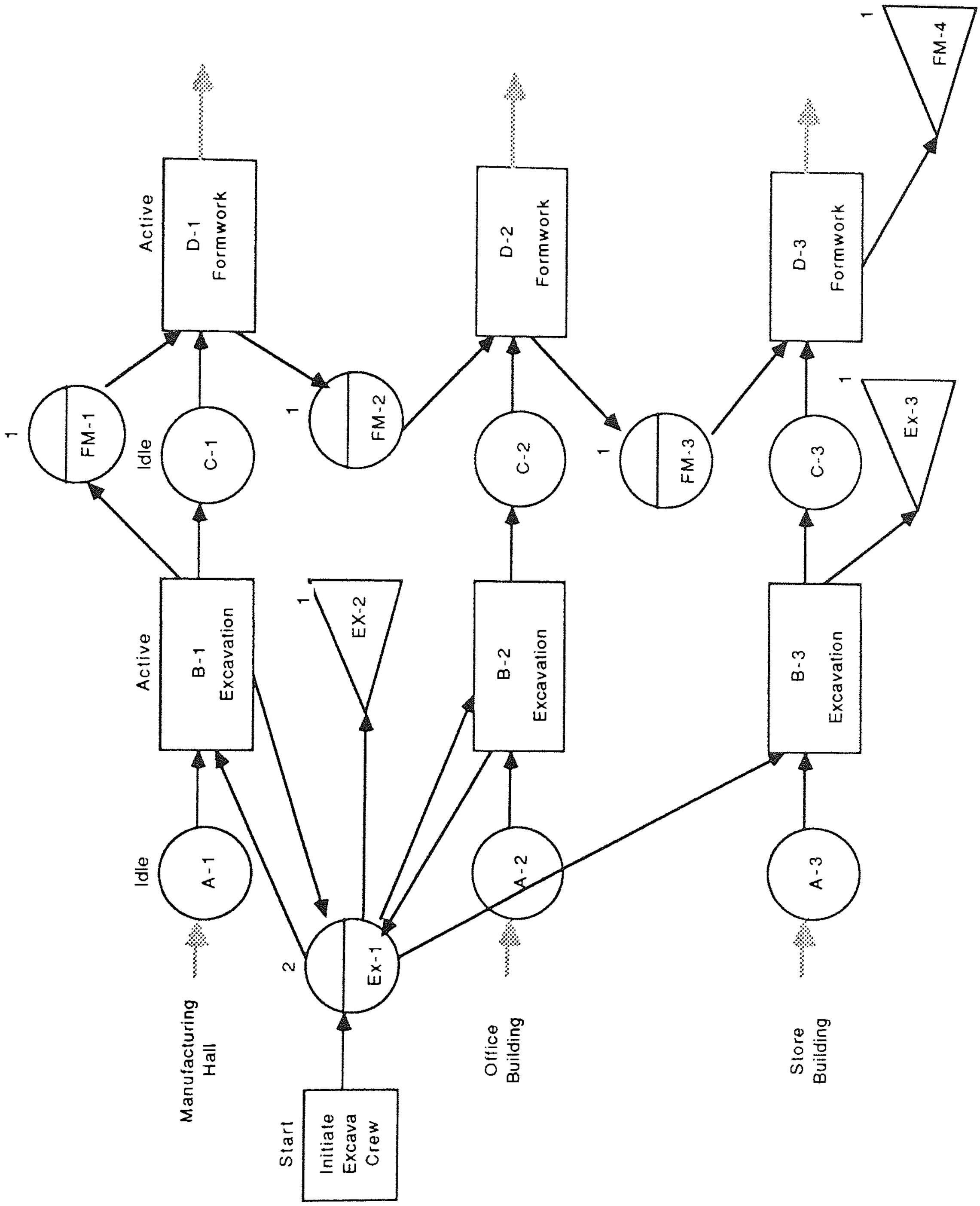

Start
Initiate Excava Crew
Manufacturing Hall
Office Building
Store Building
2
Ex-1
Idle
A-1
Active
B-1 Excavation
Idle
C-1
1
FM-1
Active
D-1 Formwork
1
FM-2
1
EX-2
A-2
B-2 Excavation
C-2
1
FM-3
D-2 Formwork
A-3
B-3 Excavation
C-3
1
Ex-3
D-3 Formwork
1
FM-4

Figure (4-2)

and so on until it finishes all formwork activities. It then leaves the site (node FM-4). At this point the following can be noted :

1-Since two excavation crews can be made available, two of the three excavation activities can be carried out in parallel, with the third being started after the finish of the smaller of the other two. This demonstrates how the preferential logic can be represented through the modelling of the flow of resources.

If three excavation crew can be made available, the three excavation activities could be done in parallel with the others.

Different possible sequencing logics for executing the work can be modelled without changing the main structure of the network. The absolute logic which controls the main structure of the network remains valid all the time, while the preferential logic can be changed by changing only the flow of the relevant resources.

2-The formwork crew may stay idle at the node (FM-2) awaiting the excavation activity (B-2) to finish and release the work location (C-2). By recording the time during which the formwork crew stays idle at the node (FM-2), the planner can observe the interaction between this resource and the excavation resources. He is then able to change the deployment point of the formwork crew, increase the size of the excavation crew, or decrease the size of the formwork crew to eliminate the idle time.

3-Each activity has two main ingredients : work location and resources. It can not start before both become available. The availability of resources, the interaction between them, and the dependencies between the activities and resources can be modelled and studied at the same time.

4.2.2.2. The Flow Of Non-Renewable Resources :

This includes all types of material.

Materials are usually ordered in bulk at discrete intervals during the construction phase. The size of the order for each type is usually large enough to keep the work going during a specific period of time, but small enough to minimize stocking and handling costs.

The flow of this resource category is simpler than the flow of the reusable resources. Materials arrive at the site in an idle state (either to a temporary store on site or to a place close to the relevant work locations). When this resource is needed, it moves to its final destination work location to become part of the end product.

Figure (4-3) shows a graphical presentation of the flow of this resource category. Since the schedule of ordering materials is by product of the activity and resources schedule, this work will not consider the flow of this resource category.
A summary of the concepts of the model is shown on figure (4-4).

As may be noted in figure (4-2), presenting all the elements of the proposed model (i.e. work locations, activities, and the flows of all required resources) on a single graph makes the network too busy. It becomes unreadable and very difficult to modify. For this reason the graphical presentation of the model is divided into two parts :

- The main network shows only the project activities (the active state of work locations) and the idle states of all work locations.

  The structure of this network is based on the absolute logic alone which defines the technological links between activities. This network remains valid throughout the execution phase.

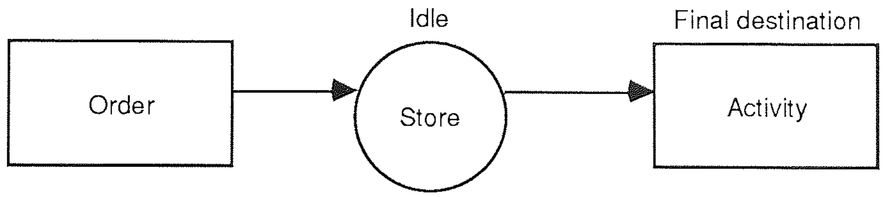


Figure (4-3)

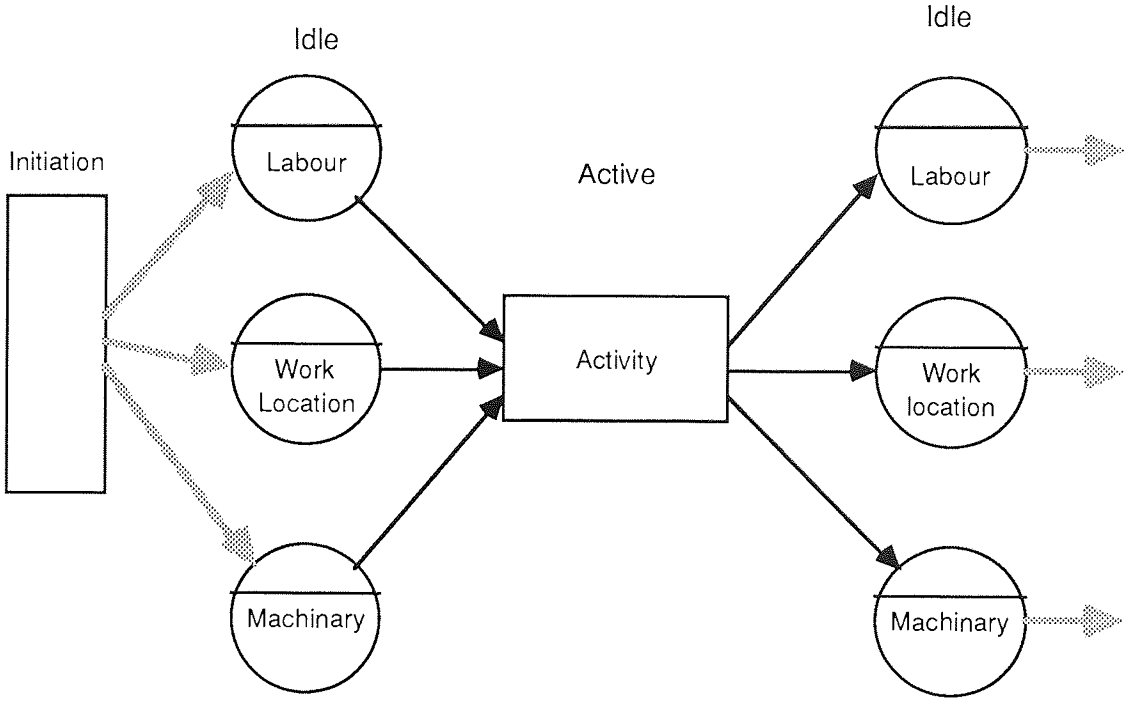


Figure (4-4)

- Small sub-networks represent the flow of a specific type of resource. Some of these may change slightly when any change occurs on site, because they are based partly on the preferential logic to define the sequence of executing the work.

Before the structure of each type of these networks is introduced, it is necessary to discuss the concept of the space queue node and the critical path as defined in the model.

4.3. The Concept Of Space Queue Node And Critical Path :

One of the main contributions of this work is the introduction of the concept of the Space Queue node (S.Q.node) and its role in defining critical path and float in the model network. This node models the idle state of each work location in the project. It records the period of time during which the work location or work space remains empty awaiting the arrival of resources which are required for performing the work at this location. The function and use of this node will become clear later in this chapter.

4.3.1. Types Of link In The Network Structure :

This model adopts the activity-on-node diagram. The structure of the network using this type of presentation consists of a set of nodes connected by a set of arrows. The start of the network is usually marked by a dummy node called a start node, and the end is marked by another dummy node called the end or terminal node. The structure of the network of any configuration has in general different types of link between its nodes. These links can be classified into four major simple types :

- Activities or nodes in chain.
- Activity or node in source.
- Activity or node in sink.
- Activity or node in dipole.

They are shown in figure (4-5).

The simple network has a small number of links. Complicated networks involve a large number of combinations of these links at several points in their structure. The number of links and combinations depends on the size of the network and the complexity of the logical sequencing of the activities the network represents. The combination of types of link may appear in one or several locations in the network, some section of the network may only have one type of simple link, other sections may have combinations of more than one type.

In practice, there are an infinite number of network configurations: An activity in source should have more attention than any other activity, because a delay in its performance halts the start of its successors. An activity in dipole has a more sensitive position in the network. It represents a bottle neck which must be carefully monitored if smooth progress at the execution phase is to be obtained. The easiest links to control are the chain and activity in sink.

4.3.2. Conventional Network Analysis :

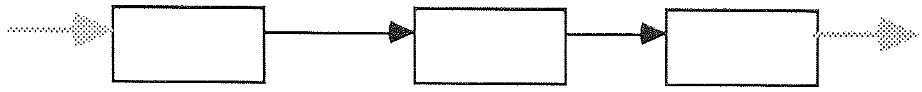
The forward calculation pass in the network analysis defines the early start (ES) and early finish (EF) of each activity and the completion time of the project.

The early start (ES_i) of an activity in sink (figure 4-5-c) is equal to the maximum early finish of its immediate predecessors, and its early finish (EF_i) is equal to its early start (ES_i)plus its estimated time duration (D_i).

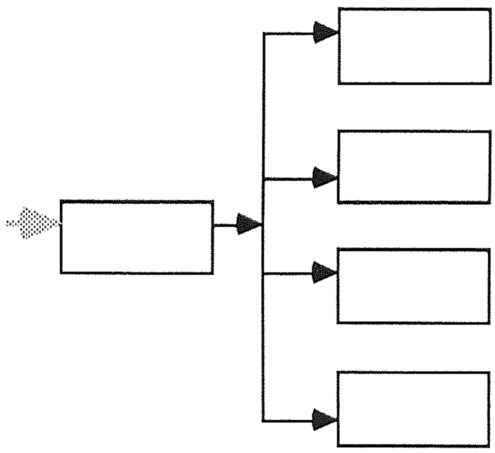
$$ES_i = \max \text{ (EF of all immediate preceding activities)} \quad (1)$$

$$EF_i = ES_i + D_i \quad (2)$$

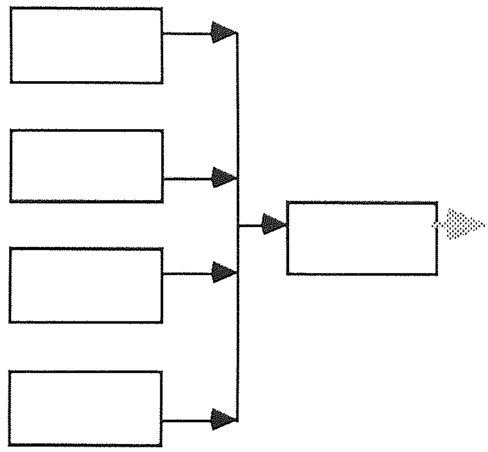
The same is true for any activity in dipole (figure 4-5-d).



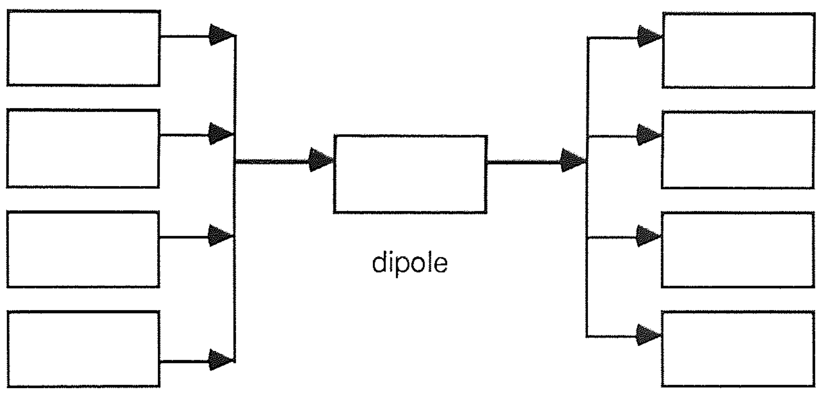
(a)-Chain.



(b)-Source.



(c)-Sink.



(d)-Dipole.

Figure (4-5)

The backward calculation pass defines the late finish (LF) and late start (LS) of each activity. The late finish of an end node (LF_e) is equal to its early (EF_e), and its late start (LS_e) is equal to its early start (ES_e).

$$LF_e=EF_e=ES_e+D_e \qquad (3)$$

$$LS_e=LF_e-D_e=ES_e \qquad (4)$$

For activities in source (figure 4-5-b) the late finish (LF_i) is equal to the minimum late (LS) of all its immediate successors, and its late start (LS_i) is equal to its late finish (LF_i) minus its estimated time duration (D_i).

$$LF_i=\min(\text{LS of all immediate succeeding activities}) \qquad (5)$$

$$LS_i=LF_i-D_i \qquad (6)$$

Again the same is true for any activity in dipole (figure 4-5-d).

The next step in the network analysis is to calculate the float on each activity and define the critical path. The total float on an activity is the spare time shared with other activities on the same chain in the network. If this time is totally consumed the following activities on the same chain become critical. The value of the total float (TF_i) on an activity is equal to the difference between either its late and early finish or its late and early start.

$$TF_i=LF_i-EF_i \qquad (7)$$

$$TF_i=LS_i-ES_i \qquad (8)$$

The free float is the flexible time available to the activity. If consumed, it will not affect the early start of any succeeding activities. The value of this type of float (FF_i) for an activity in source or dipole (figure 4-5) is equal to the minimum early start of all its successors minus its early finish.

$$FF_i=\min(\text{ES of all immediate succeeding activities})-EF_i \qquad (9)$$

Independent float is the spare time on an activity that if consumed, will not affect the early start of any succeeding activities nor the float of its immediately preceding activities.

The independent float is part of the free float, its value is equal to the free float minus the difference between the maximum late finish of all immediate preceding activities and the early start of the activity in question.

$$IDF_i=FF_i-(\text{max LF of all immediate preceding activities - } ES_i) \qquad (10)$$

In practice, a small number of activities in the network have independent float. An activity with no total float is called a critical activity. The free float is part of the total float, so an activity with no total float will not have any free float, however the opposite is not true. An activity with no free float is not necessarily critical. It may have total float. The critical path is the longest continuous path which links the start with the end of the network.

We have seen earlier (section 2.5.3.5) that it can be difficult and confusing to use the total float, as it is shared with a set of activities on the same chain. At the construction phase the independent float is useless because its value is linked to the late finish of the preceding activities (see equation 10). Earlier events on site can be recorded but have passed beyond control. Corrective actions and precautions can be taken only for future activities. So in that sense the value of independent float is redundant.

The important data for making decisions and taking corrective actions at the execution phase are the expected start of each of the following activities and the spare time available for the current activities. The free float is very valuable for control, because its magnitude is only linked to the early start of the immediate succeeding activities (see equation 9). This spare time on an activity is not shared with any other activity in the network, so the controller on site can use it without being concerned about the effects on the remainder of the work (as the case with total float).

Another important property of this float is that it can be defined through the forward pass of calculation without the need for the backward pass, as its value is based on the early start and early finish of activity times (see equation 9). While the definition of the value of the total float requires both the forward and backward calculations (see equations 7,8) which are necessary to define the critical path.

This property eliminates the need for the backward calculation during the simulation which reduces the time and cost of the network analysis. The next section shows that by using the concept of the space queue node, it is possible to record the value of the free float and define the critical path without the need for the backward calculations.

4.3.3.The Concept Of Float And Critical Path In The Model:

The discussion of the concept of float will be introduced step by step on the types of possible links in the network structure (see section 4.3.1).

1. A Chain Link :

Let us consider a simple case where the network consists of a set of activities in chain (figure 4-6). The idle state of the work locations are represented by the space queue nodes (i, and n), and the activities are represented by nodes A,B, and C.

In this type of network all the activities are critical because there is only one path in the network. If all resources required are assumed to be available when they are needed, the space queue nodes i, and n will record zero idle time through the forward calculations. Now, suppose that the resources required to conduct activity (B) are delayed, the space queue node (i) will record an idle time equal to the difference between the early start of activity (B) and early finish of activity (A). This idle time represents the value of the free float available for activity (A) (see equation 9).

This is a very interesting point, the inclusion of the availability of resources created a float on the critical path. This means that if the required resources for any activity on the critical path are expected to be delayed the immediately preceding activity which is critical will have spare time equal to the amount of delay.

Suppose this chain (figure 4-6) is part of a network, the space queue nodes (i, and n) behave in the same way described whether the chain is critical or not.

2. Source Link :

Let us consider activity (A) in a source link in a part of a network as shown on figure (4-7). The space queue nodes (i, n, and p) will record zero idle time through the forward calculation if the required resources are assumed to be available at any time.If the resources required for all succeeding activities (B, C, and D) are delayed (the extreme case), each of the space queue nodes records the delay on the relevant resource.

In this case the smallest delay recorded represent the free float for activity (A) (see equation 9). If any of the space queue nodes records zero idle time the free float available for activity (A) will be zero. If one or more of the succeeding activities are critical, activity (A) will be critical as well because the critical path is a continuous path.

So, during the analysis, is is enough to know the position of the immediately succeeding activities to decide whether or not the activity in source is critical.

3. Sink Link :

Figure (4-8) shows activity (D) which is located at a sink position in the network structure. If activity (D) is not critical and the resources required for it are assumed to be available, the space queue nodes (i, n, and p) will record the free float available for activities (A, B, and C). One of these activities will have no free float because its early finish will be equal to the early start of activity (D).

Suppose that activity (D) is critical, one of the activities (A, B, C) will be critical, and in this case the one which has obviously no free float. So the activity preceding the space queue node, which records zero idle time will be critical. Now if the resources required for activity (D) are delayed and activity (D) is critical then the activity preceding the space queue node which records minimum idle time will be critical.

Suppose that node (D) is the end of the network, in this case, the node (D) is definitely critical, because it represents the end of the critical path and its early start equals its late start. Also the activity preceding the space queue node which records the minimum or zero idle time will be on the critical path.

Using the property of the end node, the property of the critical path as a continuous path, and the feature of the space queue node, it is possible to define the critical activities and the critical path as well. This is done as follows :
After conducting the forward calculation, each space queue node recorded the free float available on its immediately preceding activity. This float is created by the technological constraints and resource constraints as well.

Now the process starts by scanning the network backward starting at the end node. The end node, as shown earlier (figure 4-8), is critical. If the end node is preceded by a chain, all the activities on that chain are critical. If it is preceded by a set of activities in parallel (figure 4-8), the activity preceding the space queue node which records minimum idle time will be on the critical path. The defined critical activity has only three possible types of link with the preceding activities :

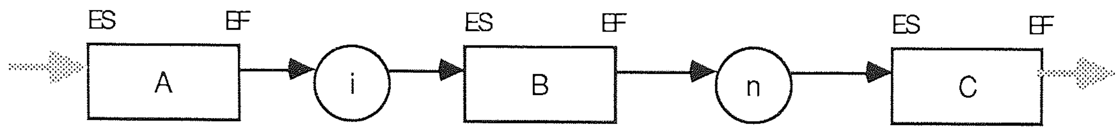


Figure (4-6)

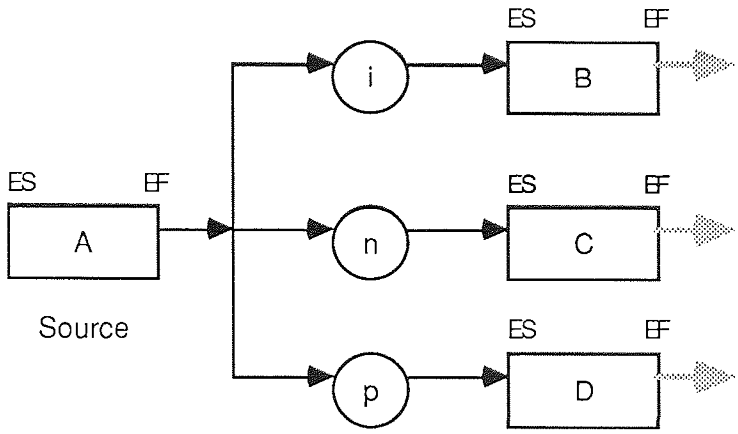


Figure (4-7)

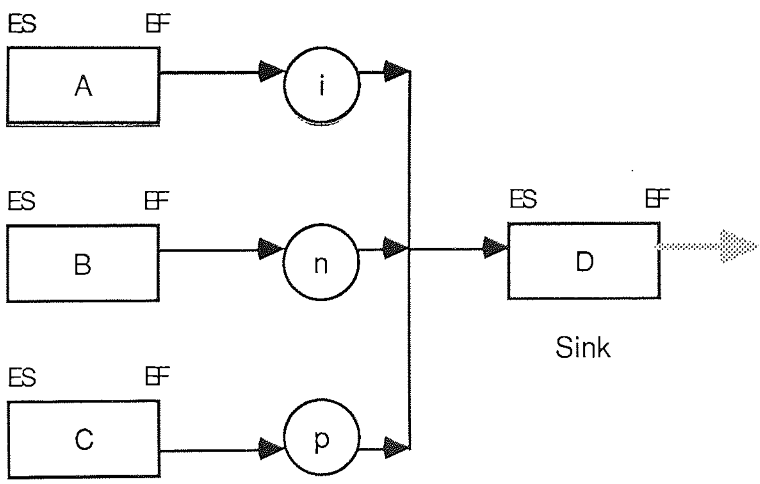


Figure (4-8)

- It may be linked to a chain.
- It may be linked to a set of activities in parallel, in this case the previous solution will be applied.
- The last possibility is for it to be linked to an activity in source (figure 4-7), in this case the activity in source will be critical.

The process continues in this fashion until it reaches the start node (which is the same as activity in source) where the critical path has been defined.

Throughout the simulation, each iteration produces a different critical path. At the end of the simulation the number of times each activity was on the critical path will be divided by the number of iterations to work out the criticality index of each of the project activities.

4.4. The Structure Of The Main Network :

As mentioned earlier, the main network represents the project activities, the idle states of the work locations and the milestones in the project. The structure of this network is based on five modelling elements :

- Activity nodes,
- Milestone nodes,
- Space queue nodes,
- Function nodes, and
- Arcs.

The symbols and the label of the logic of each of these elements are shown in figure (4-9).

4.4.1. Activity Nodes :

There are two types of nodes to represent project activities :

COMBINATION and NORMAL.

COMBINATION Node :

This node is used in CYCLONE to model a work task that has ingredient constraints on the mix of resources that must be available before the work task commences [58, pp-84].

The symbol of this node is a square with a corner slash (figure 4-9-a). It has AND input logic and ALL output logic. This node is used in the current model to represent an activity that has two constraints : work space or location and other physical resources.

It is used in the same sense as in CYCLONE with the following features added to it:

- The node has to be preceded by at least two queue nodes :

  one represents the availability of the work location, the other represents the availability of the resources.
- It has two sets of cost :

  Primary cost which includes the cost of materials and the cost of the other resources (labour and machinery) incurred during the work it represents.

  Cumulative cost which is passed to it from the incoming flow carried by the immediately preceding space queue node.
- It is capable of working out the variable cost of resources (labour and machinery), added to the material cost and the cumulative cost. It then passes the total to the out-going flow through one of the immediately succeeding space queue nodes or accumulator nodes.

  This node is used to represent all those types of activities :

excavation, formwork, plastering ...etc. which require both the workspace and resources.

As with CYCLONE the time duration of this node is a user defined function. It can be specified either as a constant or as random values represented by a probability distribution (several types of distribution are built into the structure of the model. This will be explained in chapter five).

<u>NORMAL Node :</u>

The symbol of this node is a square (figure 4-9-a). It is used in CYCLONE to model unconstrained work tasks. Thus a resource entity arriving at the input side of this node is given free access to initiate work task processing for a period of time that is user-defined [58, pp-82].

In the current model it is used to describe any activity which does not consume any physical resources such as : the curing of concrete , the settlement period of the soil under the foundation layer of the road... etc.

The logic controlling this node is the same as of the COMBINATION node except that the NORMAL node is preceded by only one node and can not be preceded by either a space queue node nor a resource queue node.

Since it does not consume physical resources, the node records only cumulative costs. It receives the cost accumulated through the incoming flow and passes it to the outgoing flow.

4.4.2. Milestone Node :

These nodes are used to model the start and the end of the project, also the end of each important part of the project. They use the concept of split-logic which is used by the VERT network [74].

There are two input logics for these nodes : INITIAL and AND, and seven output logics : ALL; FILTER-1,2,3; and TERMINAL-1,2,3. The combination of these logics are shown on figure (4-9-b). The symbol of each of these node is a rectangle divided into three sections. The horizontal section is used for the node's label, and the vertical sections are used to label the input and output logic. The duration of all these nodes is zero.

1. INITIAL-ALL Node :

This is used to initialize the start of the project. In the current model only one start node can be used, while in VERT several nodes may be used. This node can be assigned two parameters : time and cost.The assigned time is the date when the project is to start, and the cost is the initial cost of moving in at the start of the work. The node initializes the necessary work locations and resources for the starting activities.

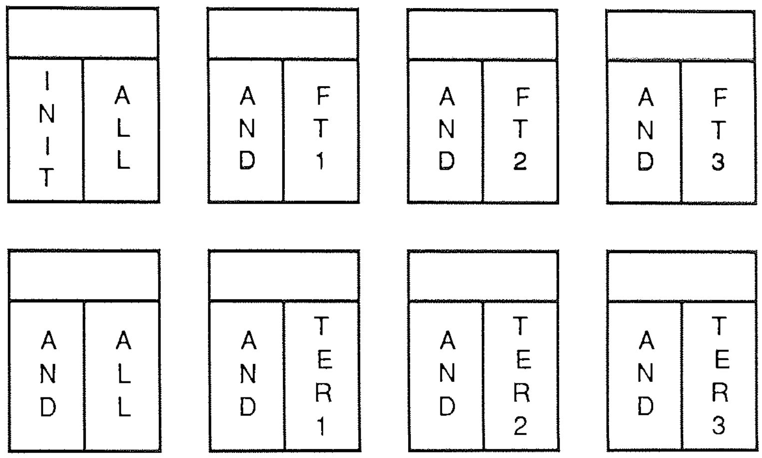
2. AND-ALL Node :

This node has AND input logic and ALL output logic. In VERT the AND logic Is defined as follows :

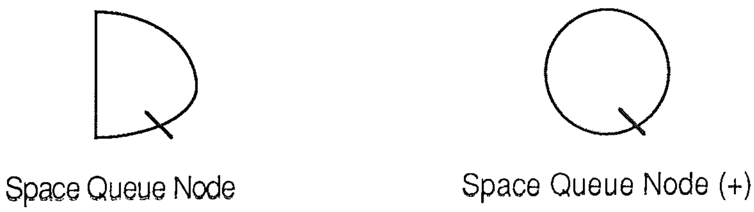
AND input logic requires all its input arcs to be successfully completed before the combined input network flow is transferred to the output logic for the appropriate distribution among the output arcs. If at least one of the input arcs is failure, the network flow will be sent out to the escape arc.

The time computed for the nodes bearing AND input logic is computed as the maximum cumulative time of all the input arcs. Cost and performance are computed as the sum of all the cumulative cost and performance values of all the input arcs. ALL output logic is defined in VERT as output logic which simultaneously initiates the processing of all output arcs.

(a)-Activity Nodes.



(b)-Milestone Nodes.



(c)-Space Queue Nodes.

(d)-Function Nodes.

Figure (4-9)

In the current model the function of AND logic is defined as follows: AND input logic requires all the immediate preceding nodes to be finished or realized before it can transfer the flow to the output logic. The realization time of the node bearing AND input logic is equal to the maximum finishing or realization time of the immediately preceding nodes.

The cost transferred through the node with AND input logic is equal to the sum of all cumulative cost carried by the immediately preceding nodes. ALL logic is the output logic which initializes simultaneously the start of all immediately succeeding nodes.

It transfers the cumulative cost to the appropriate succeeding node. This type of node (AND-ALL) is used to link the flow through the network or to mark the end of any phase in the project. Figure (4-10) shows an example of using this node. In this figure node (D) will be realized when all the space queue nodes (1,2,3) are realized.

It accumulates the cost carried by all these space queue nodes and transfers the sum to the space queue node (4). It initializes simultaneously the space queue nodes 4, and 5.

3. AND-FILTER Nodes :

This type of node is used in the model only to represent the end of a stage at the construction phase. These nodes have AND input logic. The function of this logic is as defined in the previous section of AND-ALL node. They have FILTER output logic with a function quite different from that defined in VERT. FILTER output logics are defined in VERT as follows :

They can initiate one or a multiple number of output arcs, depending on the joint or singular satisfaction of time/ or cost/ and or performance constraints placed on this node's output arcs.

The difference between the three types of FILTERs (1,2,3) is in the number of constraints put on the output arcs and the type of input logic each can have. In the current model the definition of the FILTER output logics are simplified to suit the technique.

The function of FILTER in this work is the same as the function of ALL logic with extra facility.

FILTER-1:

FILTER-1 is assigned a time constraint, so when it receives the flow from AND input logic, it compares the realization time of the node with the time constraint put on it. If the realization time is less than or equal to the time constraint, FILTER-1 triggers a built in register to add one to the register value. If the realization time is more than the time constraint, the register will add zero. In both cases FILTER-1 initiates the start of all succeeding nodes and passes the cumulative cost to the appropriate succeeding node.

At the end of the simulation experiment the value of the register will be divided by the number of iterations to give the probability of realizing the node with time less than or equal to the time constraint.

FILTER-2 :

FILTER-2 has the same function but in relation to the cost constraint.

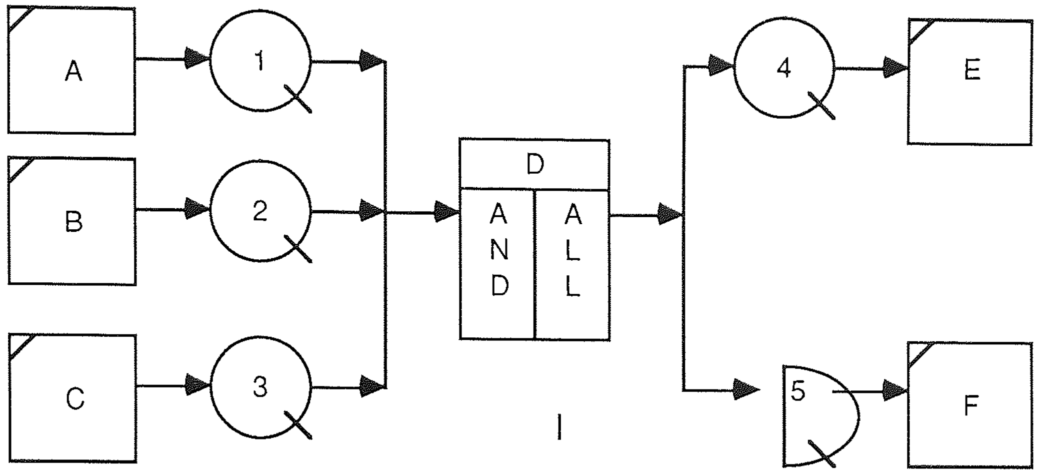


Figure (4-10)

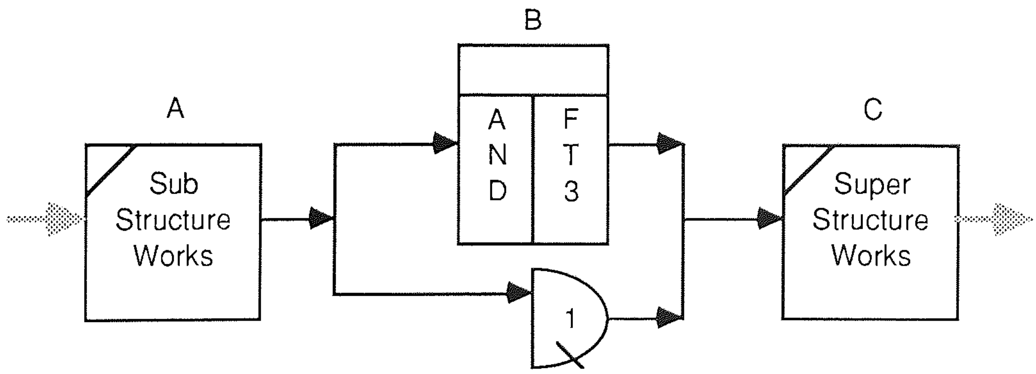


Figure (4-11)

FILTER-3 :

FILTER-3 has both time and cost constraints. Figure (4-11) shows an example of using this type of node. Suppose node (A) represents all substructure works, and node (C) represents all superstructure works in a building project. Node (B) (AND-FILTER-3) represents the end of the substructure work. If it was estimated that the substructure work was to be finished within (X) days and (Y) units of currency, (X) days will be the time constraint, and (Y) units of currency will be the cost constraint.

The milestone (B) through the simulation will register the number of times the finishing time and cost of the substructure work did not exceed the time and cost limits.

The analysis will work out the probability of achieving these targets.

4. AND-TERMINAL Nodes :

This type of node is used to mark the end of the project. AND input logic is used as defined in AND-ALL nodes. TERMINAL output logic is defined in VERT as follows:

TERMINAL output logic serves as an end point for the network. It is a sink for network flow(s). TERMINAL nodes can be given a class designation, which allows for optimization within a class as a function of time and or/ cost/ or performance values carried by the active terminal nodes.

In VERT several terminal nodes can be used for the same network, while for the proposed technique only one terminal node is allowed. The TERMINAL output logic is simplified and extra functions are added to it to suit the proposed model. Three types of TERMINAL output logic are defined:

TERMINAL-1 :

It works as a sink for the network to mark the end of the project works. At each iteration, it receives the accumulated total net cost of the work and registers its value, and the value of the realization time of the project as a whole which is equal to the realization time of AND input logic.

It accumulates the total cost of the idle time of all used resources and registers this value. At the end of the simulation, this node will have data recording the realization time of the project, the total cost of idle resources, the total net cost of the work, and the total cost including the cost of the idle time. TERMINAL-1 has a time constraint which is defined by the user. It has a register which works in the same fashion as the register of FILTER-1.

TERMINAL-2 :

It has the same function as TERMINAL-1 except that TERMINAL-2 has a cost constraint and two cost registers. One is to record whether the total net cost is less than or equal to the cost constraint, the other is to compare the total gross cost with the cost constraint.

TERMINAL-3 :

It has two constraints (time and cost), and three registers one for the time parameter, and the other two for cost. With the exception of AND-TERMINAL-1,2,3, all other activity nodes (COMBINATION and NORMAL) and milestone nodes (AND-ALL and AND-FILTER-1,2,3) can initiate the deployment of resources at any point in the network. The relationships between all the modelling elements of this technique will be introduced diagrammatically at the end of this chapter.

4.4.3. Space Queue Nodes:

The idea of the Queue node is borrowed from CYCLONE. In CYCLONE the Queue node is used to model the idle state of a resource entity [58, pp-86].

In the proposed technique the function of this node is modified to represent the idle state of the work location. VERT models the cost in a very complicated way. In the current model the author created two types of Queue nodes to serve the purpose of modelling and accumulating the cost throughout the network. They are:

Space Queue node and Space Queue node (+) with cost function.

Space Queue Node (without cost function):

The symbol of this node is half a circle with a slash at the bottom right side corner (figure 4-9-c). It represents the idle state of a work location. Its function in the network is to model the technological logic (absolute logic) of the sequencing of the project activities. The time duration recorded by this node is produced during the running of the model. It records statistics on the idle time experienced by the work location waiting to be occupied by the resource required to achieve a specific activity.

It receives the flow from its immediately preceding node and holds it until the conditions of the immediately succeeding node are met. Then it releases the flow to the next following node. The statistics of the idle time recorded by this node are the probable values of the free float available for the immediately preceding node (being activity or milestone node).

Space Queue Node (+)(with cost function):

The symbol of this node is a circle with a slash on the right hand side bottom corner (figure 4-9-c). It has the same feature as the previous Queue node except that it has the following extra function: It receives the accumulated cost carried by its preceding node, and passes it to its succeeding node when the conditions of this succeeding node are satisfied. Figure (4-12) shows an example of the use of these types of nodes.

In this figure node(A) represents plastering works, nodes B,C, and D represent the 2nd fixing works and painting, nodes 1 to 6 represent the idle state of work locations. Because cost is an additive function, it is not possible to pass the cumulative cost to all parts. This is the reason for using two different types of Space Queue node.

The cumulative cost carried by node (A) will be passed only to the Space Queue node (1) which in turn passes this cost to node (B). The other Queue nodes 2 and 3 represent only the idle state of the work location pending the start of the activities C, and D. The costs incurred by the work achieved by activity C and D are passed to the Space Queue nodes 5 and 6.

In VERT, in order to model the cost, the user has to define a very complicated relationship between different arcs in the network.

4.4.4. Function Nodes :

In CYCLONE several function nodes are used, each has a predefined function in the network such as : GENERATE, CONSOLIDATE, STATISTICS, MARK, ACCUMULATOR, and BETWEEN functions [58,pp- 93].

ACCUMULATOR in CYCLONE has a counter function. It is used to count the number of units produced by the system . In the proposed model two function nodes are used: the BETWEEN node and the ACCUMULATOR node.

BETWEEN Node :

The symbol of this node is a circle with BT label to mark the node as a BETWEEN node . This node is used to represent the cost of any type of resource shared by more than one trade.

For example, the crane in a building project is usually shared by the majority of trades. It is difficult to assign the operational cost of this resource to the project activities. Another case is the site overhead cost. It is also difficult to divide this cost by all the project's activities. This node can be assigned the cost/time unit of the resource it represents.

Throughout the simulation it records the difference between the time at which it passes the cost to its succeeding node and the time at which it is initialized. Then it works out the cost incurred during this time by multiplying the cost/time unit by the amount of time it has recorded. It keeps this total cost in its record as one sample and passes it to the succeeding node. At the end of simulation, this node will have data on the total cost incurred throughout the simulation run. Figure (4-13) shows an example of the use of this node.

On this figure nodes (S) and (E) represent the start and the end of the project. Node(BT) represents the site overhead cost. When the project starts, the node(BT) marks the start date, and when the project ends it marks the end date. It then works out the duration, multiplies it by the cost/time unit to obtain the total overhead cost of the site. Then it passes this total cost to the TERMINAL node(E), and maintains a record of this cost. At the end of simulation the analysis will produce the mean value of this type of cost.

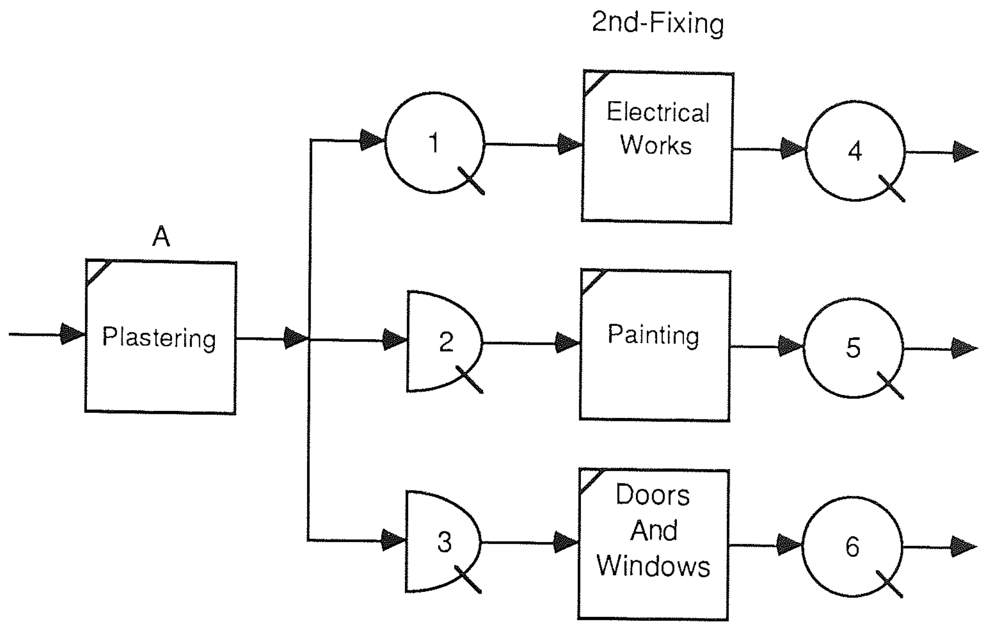


Figure (4-12)

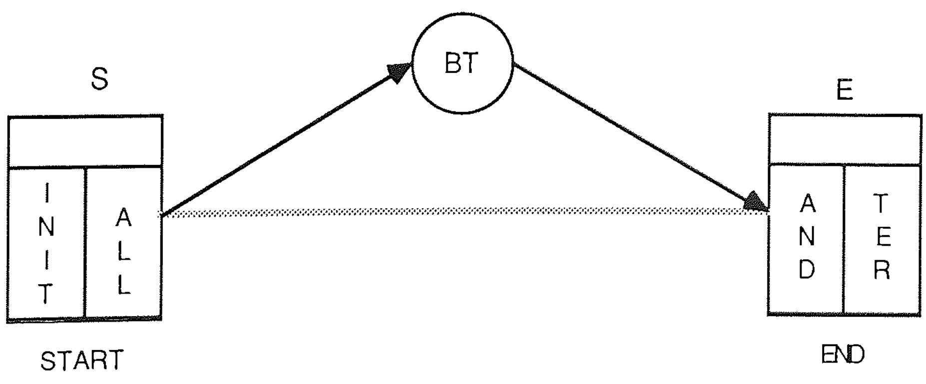


Figure (4-13)

ACCUMULATOR Node :

In a construction project, it is very useful to have information on the cost of each stage of the construction phase. This type of node is created to serve this situation.

The symbol is a circle with an (ACC) label to mark it as an ACCUMULATOR function node. The function of this node is to receive the accumulated cost carried by any node in the network and accumulate it with other received costs then pass it to any identified node in the network. Figure (4-14) shows how this node can be used.

In this figure node(A) represents the substructure work, node(B) the superstructure work, nodes (M-1) and (M-2) the end of these two stages, node(E) the end of the project. The milestone (M-1) receives the accumulated cost of the substructure work and passes it to the accumulator node.

The milestone (M-2) only receives the accumulated cost of the superstructure work and passes it to the ACCUMULATOR node. In this case, the user can evaluate the total cost of each stage instead of evaluating the total cost of all stages mixed together.

The ACCUMULATOR node adds up these costs and passes the sum to the TERMINAL node (E).

4.5. The Structure Of Resource Networks :

This type of network is used to represent the flow of each type of resource. It is designed separately to make the network presentation readable, manageable, and easy to change and understand. This network uses activity nodes (which are used in the main network) to model the active states of the resource and to initiate the deployment of the resource in question.

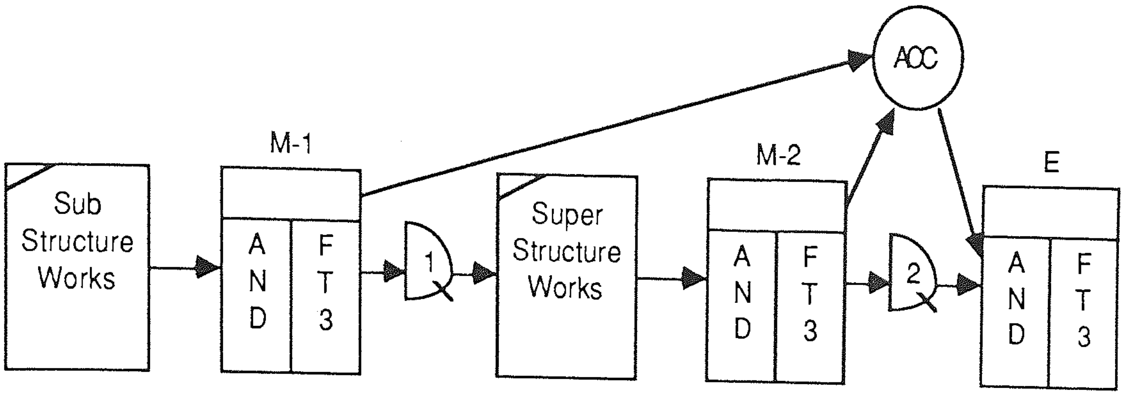
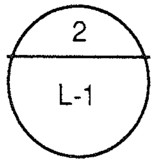
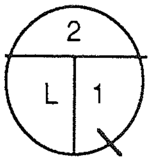


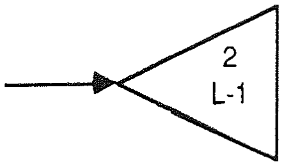
Figure (4-14)



(a)-R.Q.Node
Single-Successor



(b)-R.Q.Node
Multi-Successors



(c)-SINK Node

Figure (4-15)

The milestone and start nodes are used to initiate the resource as well. The idle state of the resource is modelled by using two types of Queue nodes : A Resource Queue node with Single Successor and a Resource Queue node with Multiple Successors. The resource leaves the site at a SINK node.

1.Resource Queue Node (with a Single Successor) :

The symbol of this node is a circle divided into two parts (figure 4-15-a). The top is used for the node's number, and the bottom part is used to mark the type of resource this node represents. For example, (L) for labour, (M) for machinery ...etc.

This node is used when the resource flows through activities which have to be conducted in serial fashion. It receives the flow of the resource either from the node which initiates the deployment of this resource or from an activity node which represents the active state of this resource. The node records the time at which the resource arrives .

The resource stays idle in this node until the work location and other ingredients of the next following activity become available. Then the node releases this resource to flow to its next active state, and calculates the difference between the arrival time and the release time, and multiplies the value by the number of resource unit that stayed idle in this node. In other words, the node produces the idle man or gang or machine.unit of time (i.e. man.days, gang.days, crew.days.. etc).

It stores this information for each iteration, so that at the end of the simulation, it will have statistics on the idle time of the resource it represents at this point in the network. At each iteration, the idle time recorded by all Resource Queue nodes of each resource network will be multiplied by the cost/ unit of the resource in question to obtain the total cost of its idle time. Then the cost of the idle time of all involved resources will be accumulated and passed to the TERMINAL node.

2. Resource Queue Node (with Multi-Successors) :

The symbol of this node is the same as the previous node but with an additional vertical line in the middle and slash at the base (figure 4-15-b). This node is used when a number of activities can be carried out in parallel. It receives the flow of the resource from its preceding node and captures the flow until the conditions of one of its succeeding nodes are satisfied.

Then it channels the number of required units of the resource to the following activity. If the number of units required by the following activity is less than the number of units available, the number of units left in this node will be used to calculate the idle time of these units alone. When the conditions of any other following activity are satisfied the node will channel the required number of units to this following activity.

When the resource completes the work required by the following activity, it will return to the node to await another activity, and this continues until all the following activities are realized. This process is controlled by a built-in priority function linked with the nodes' number of following activities. If there is any SINK node among the following nodes, it will have the lowest priority.

When all the following activities are realized and the resource has left the node to continue its flow the node will work out the idle time in terms of resource unit.time units (e.g. gang.days), and the cost of this idle time will be calculated and passed to the TERMINAL node at the end of each iteration. This is done in the same fashion as with the previous Resource Queue node.

3. SINK Node :

The SINK node is represented by a triangle. Its number and the label of the resource it represents are written inside its symbol (figure 4-15-c). This node is used to mark the end of the work for a particular resource in the project. This node registers the time at which the flow of the resource arrives at it.

This time represents the point at which the resource can be released from the site. The node collects statistics on this parameter, so the user will have information on the probable date at which a specific amount of a particular resource can be released.

At this point, a simple example is drawn from figure (4-2) to illustrate the functions of the Resource Queue nodes and SINK node. Figure (4-16) shows the flow of the formwork crew through the formwork activities for the foundations in the manufacturing hall, office building and in the store building of an industrial project.

In this figure the formwork crew is initiated at the end of the excavation activity in the manufacturing hall. The crew flows to the RQ-node (2) and waits until the conditions of activity (A) are met. Then it moves to node (A) to achieve the foundation formwork activity in the manufacturing hall. It flows in the same fashion until it reaches the SINK node (8) where it leaves the site.

Figure(4-17) shows the flow of this type of resource, but assumes that two crews are available and activities (A) and (B) can be conducted in parallel. The number on the top of the RQ-node (2) and SINK nodes (4) and (6) represents the number of crew. When the two crews are initiated, they stay at node (2) until the conditions of any of the following activities (A,B,C) are met.

Each of the crew moves to (A) and (B), the first crew to finish its activity flows back to RQ-node (2) then to activity (C), the other crew when it finishes its activity, returns to RQ-node (2) then exits the site at the SINK node (4). When the other crew finishes activity (C), it exits the site at the SINK node(6). The priority at the RQ-node (2) is assigned first to activity (A), secondly to activity (B), thirdly to activity (C), and finally to the SINK node(4).

4.6. The Relationships Between The Modeling Elements:

Figures (4-18) to (4-26) show the types of nodes which can precede and succeed each of the nodes used by the model.

It has to be emphasized here that any node can not precede or succeed itself.

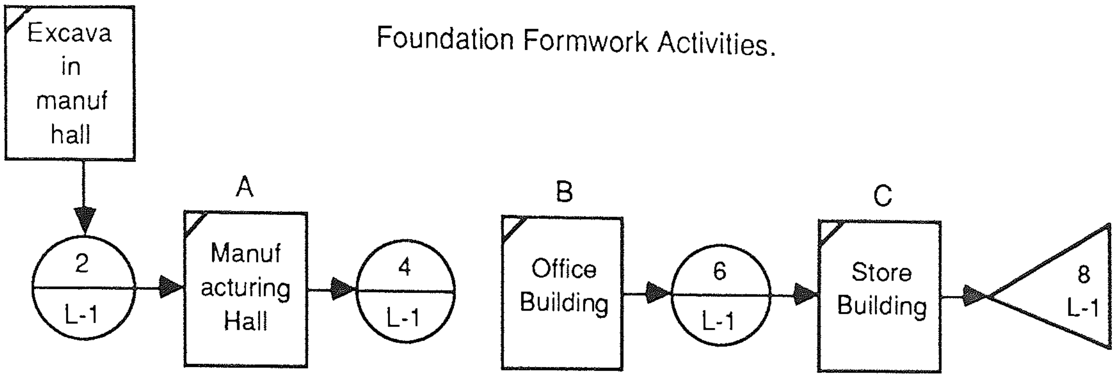


Figure (4-16)

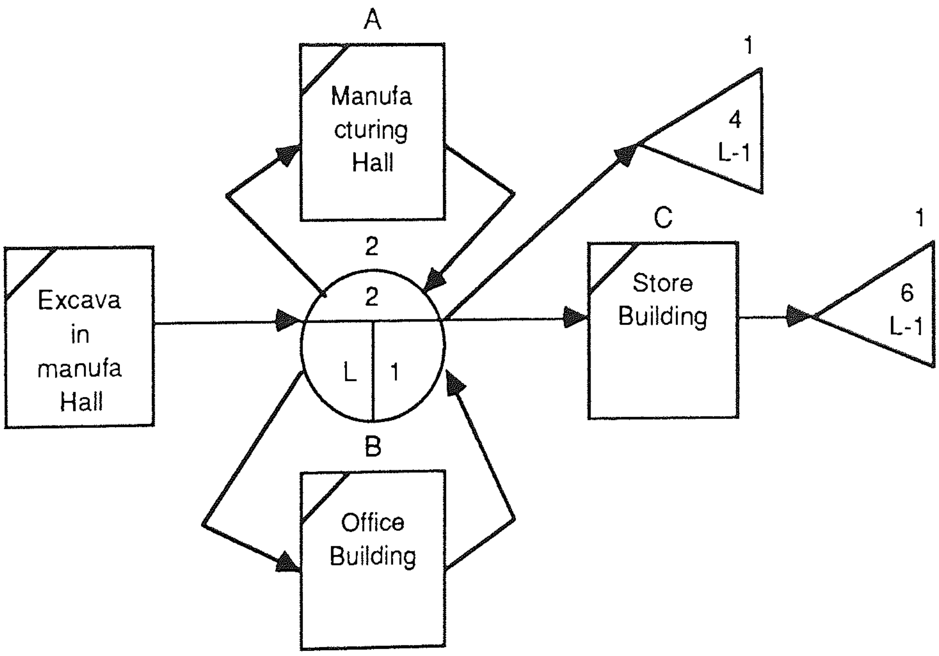


Figure (4-17)

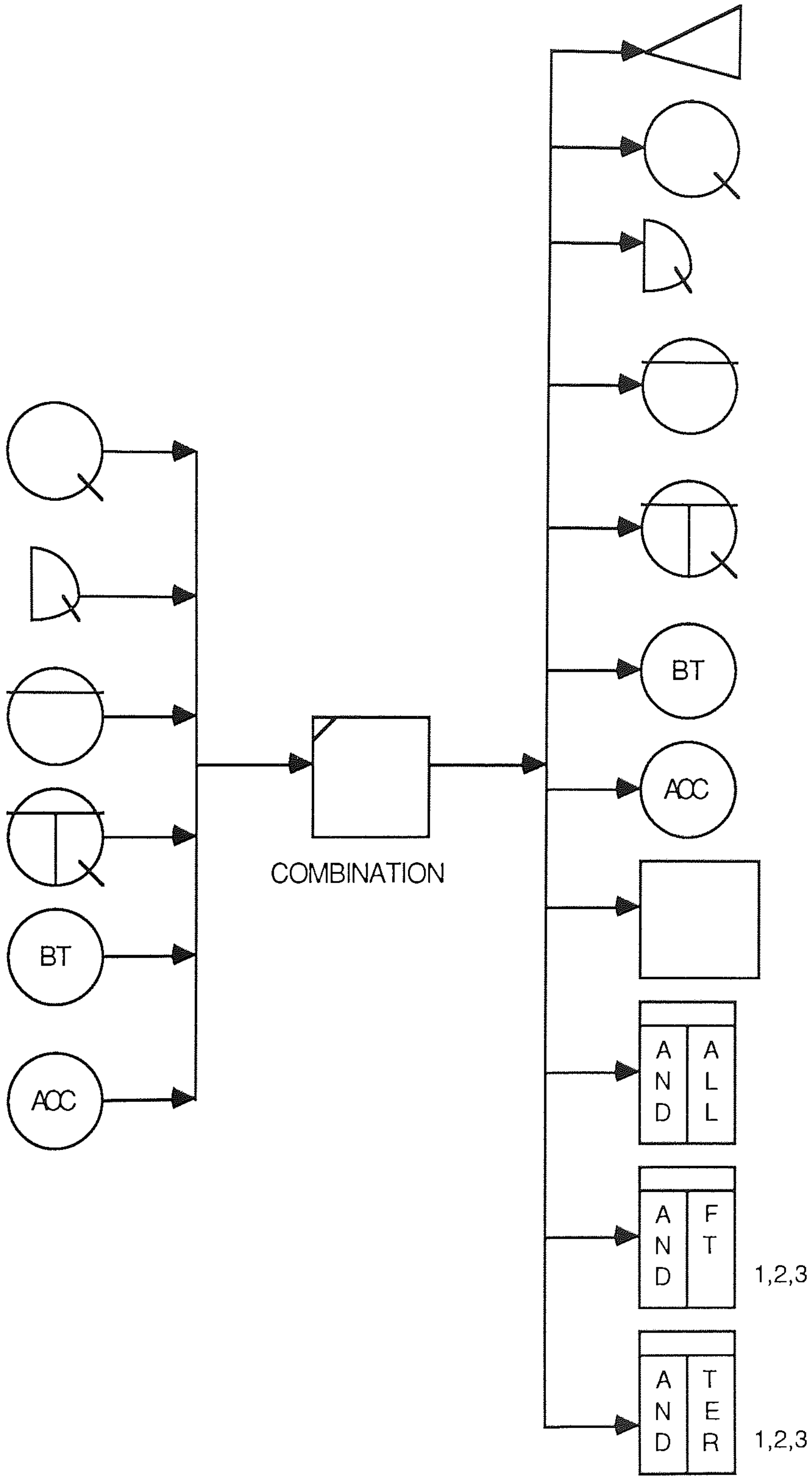


Figure (4-18)

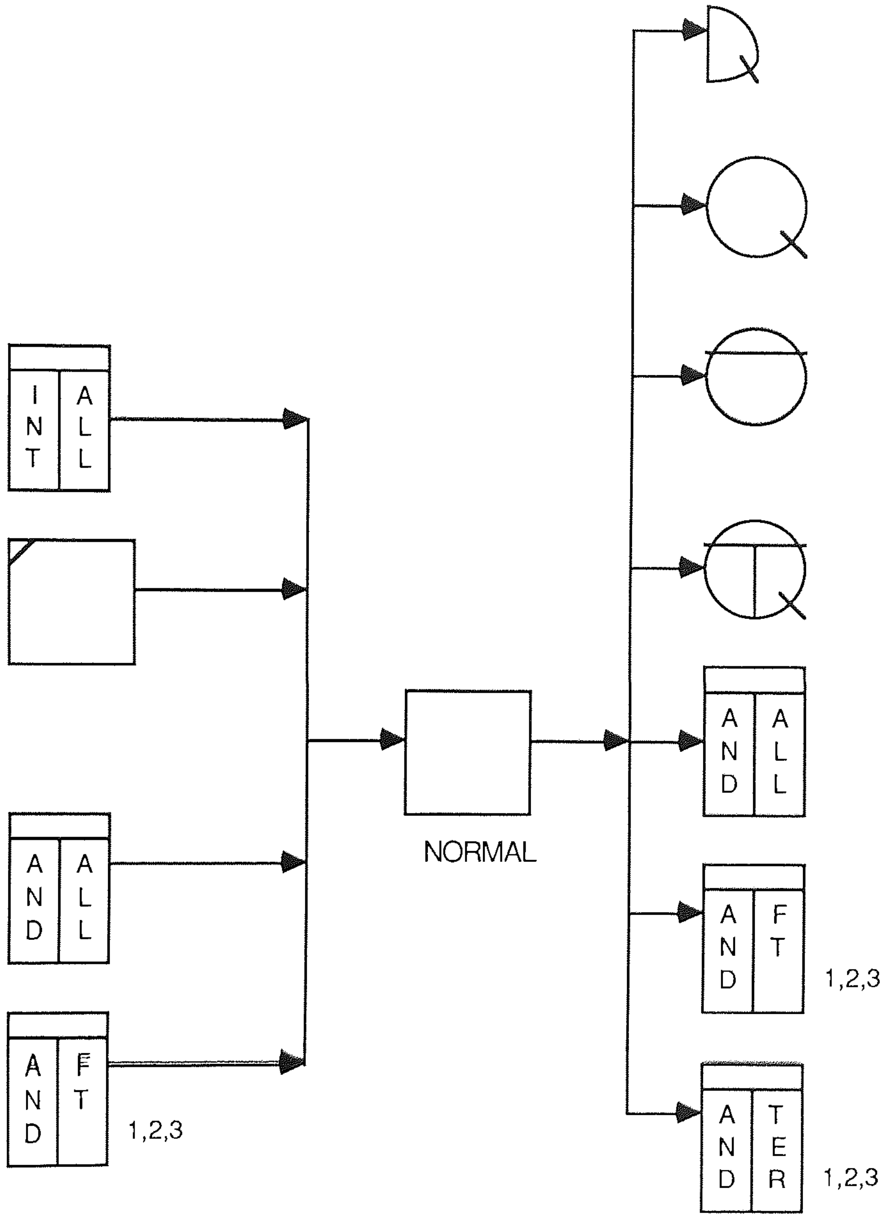


Figure (4-19)

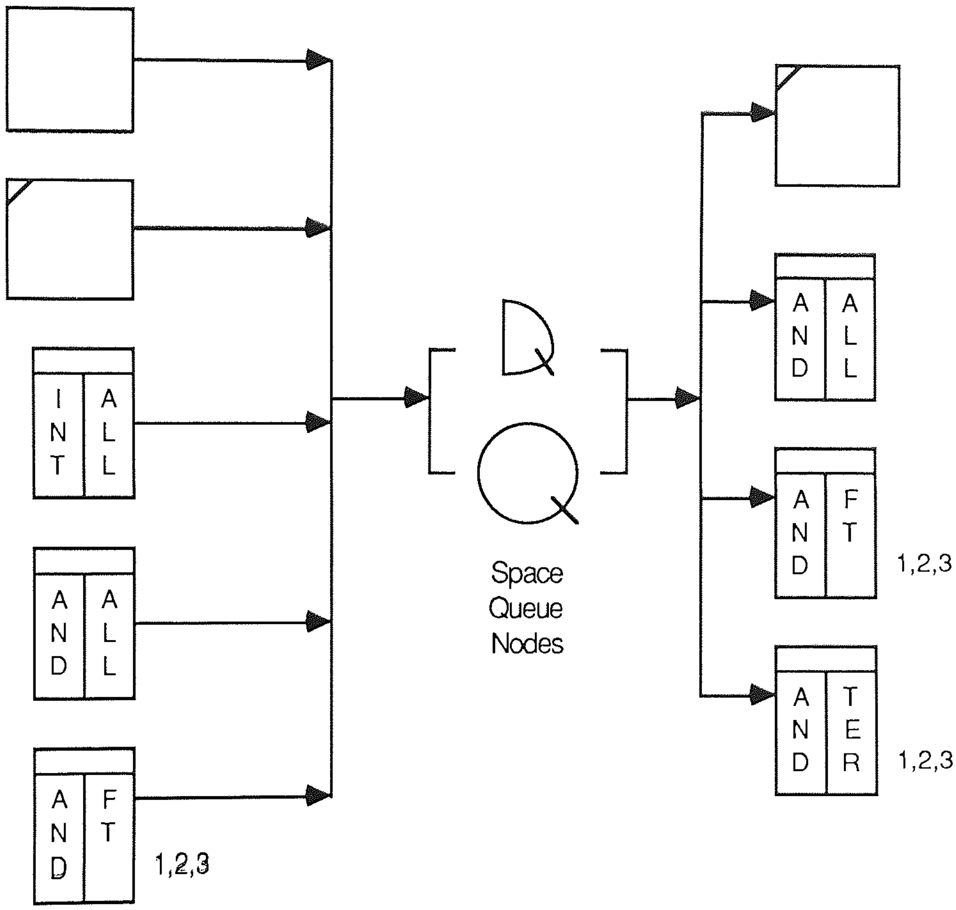

I N T
A L L
A N D
A L L
A N D
F T
1,2,3
Space
Queue
Nodes
A N D
A L L
A N D
F T
1,2,3
A N D
T E R
1,2,3

Figure (4-20)

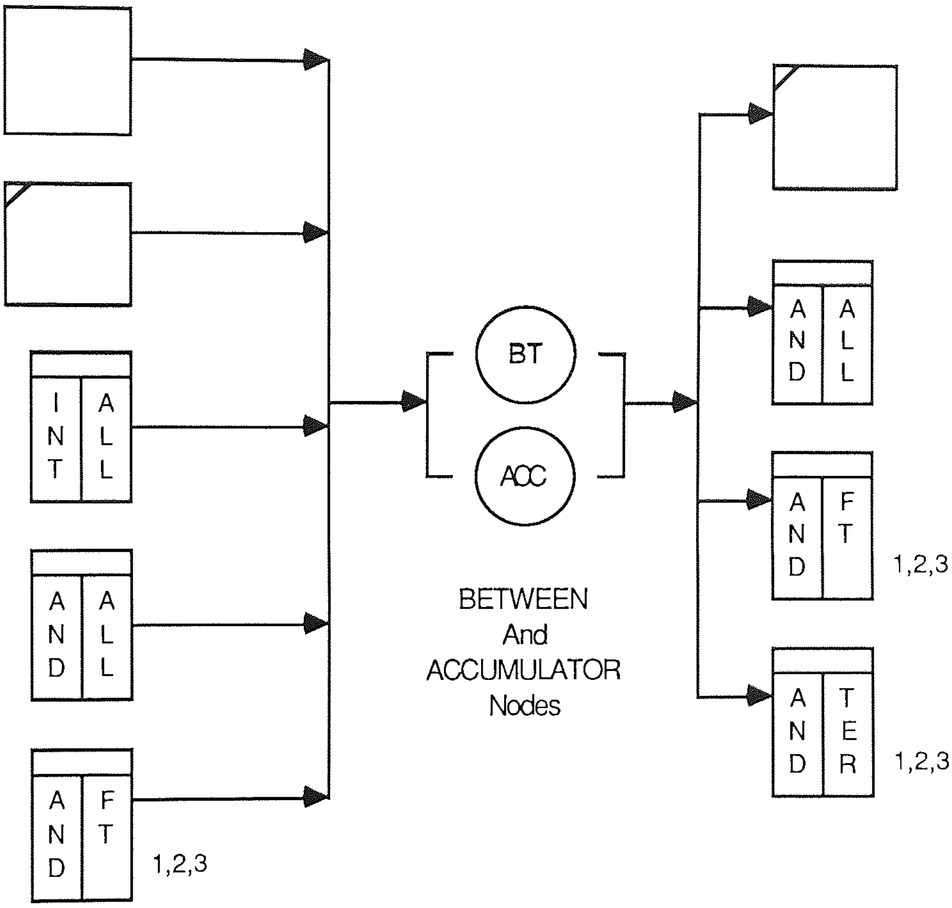

I N T
A L L
A N D
A L L
A N D
F T
1,2,3
BT
ACC
BETWEEN
And
ACCUMULATOR
Nodes
A N D
A L L
A N D
F T
1,2,3
A N D
T E R
1,2,3

Figure (4-21)

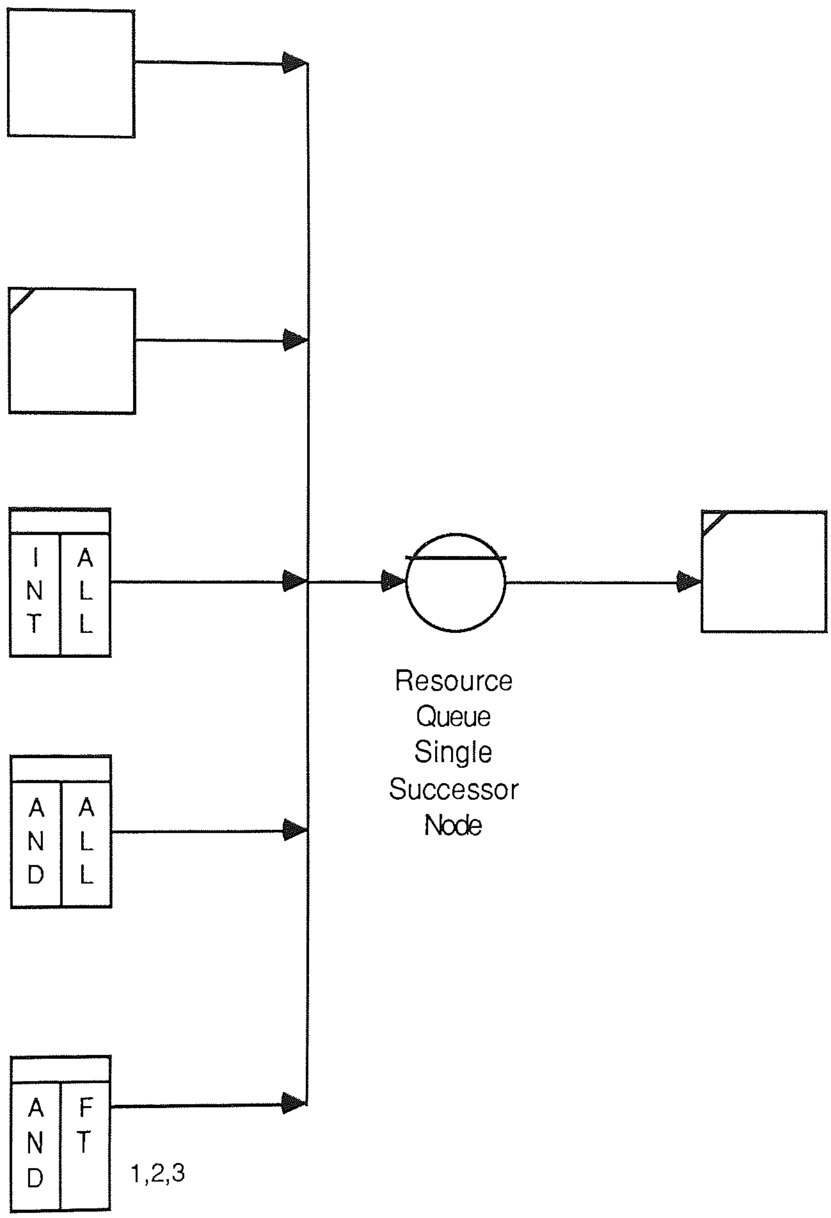

I N T
A L L
A N D
A L L
A N D
F T
1,2,3
Resource
Queue
Single
Successor
Node

Figure (4-22)

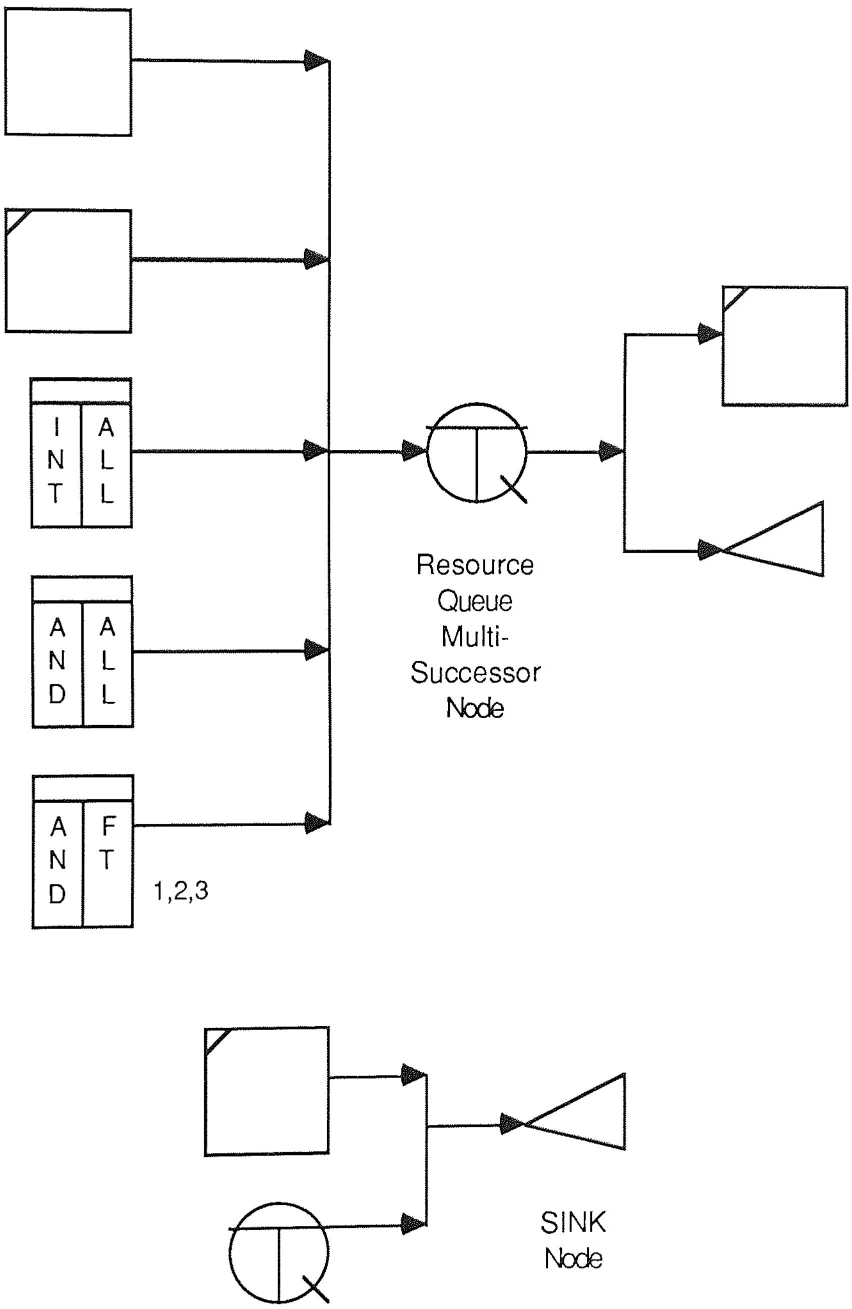

INT
ALL
AND
ALL
AND
FT
1,2,3
Resource
Queue
Multi-
Successor
Node
SINK
Node

Figure (4-23)

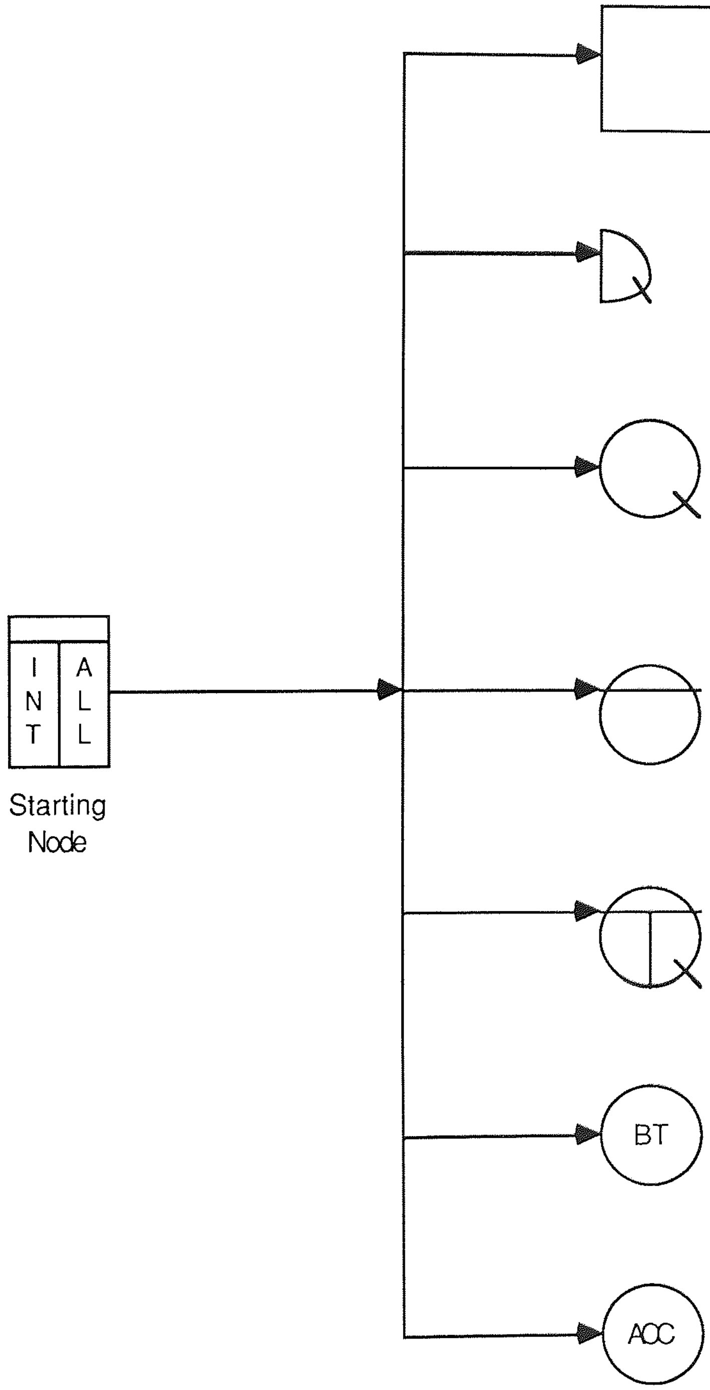


Figure (4-24)

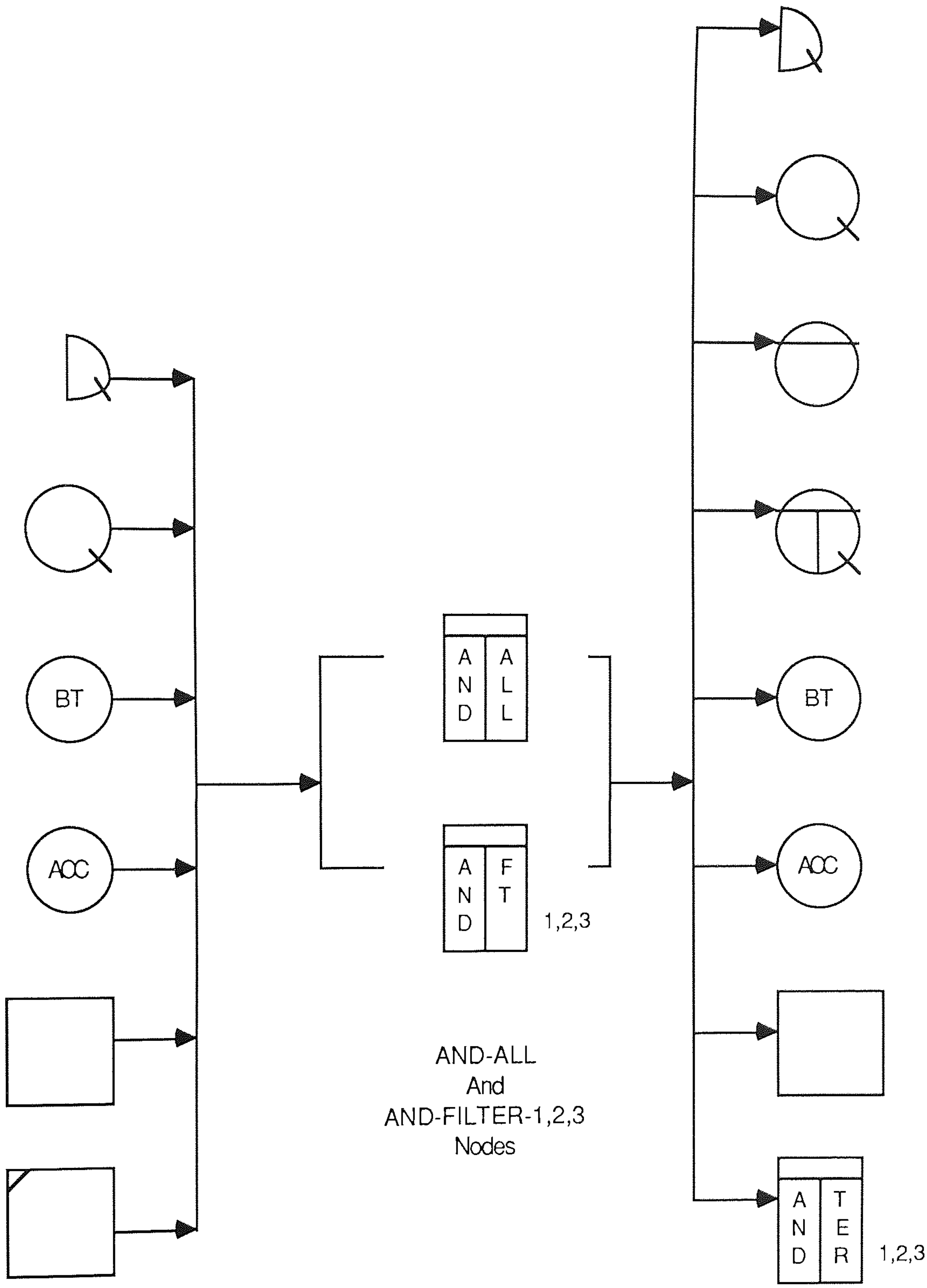

BT
ACC
A N D
A L L
A N D
F T
1,2,3
AND-ALL
And
AND-FILTER-1,2,3
Nodes
BT
ACC
A N D
T E R
1,2,3

Figure (4-25)

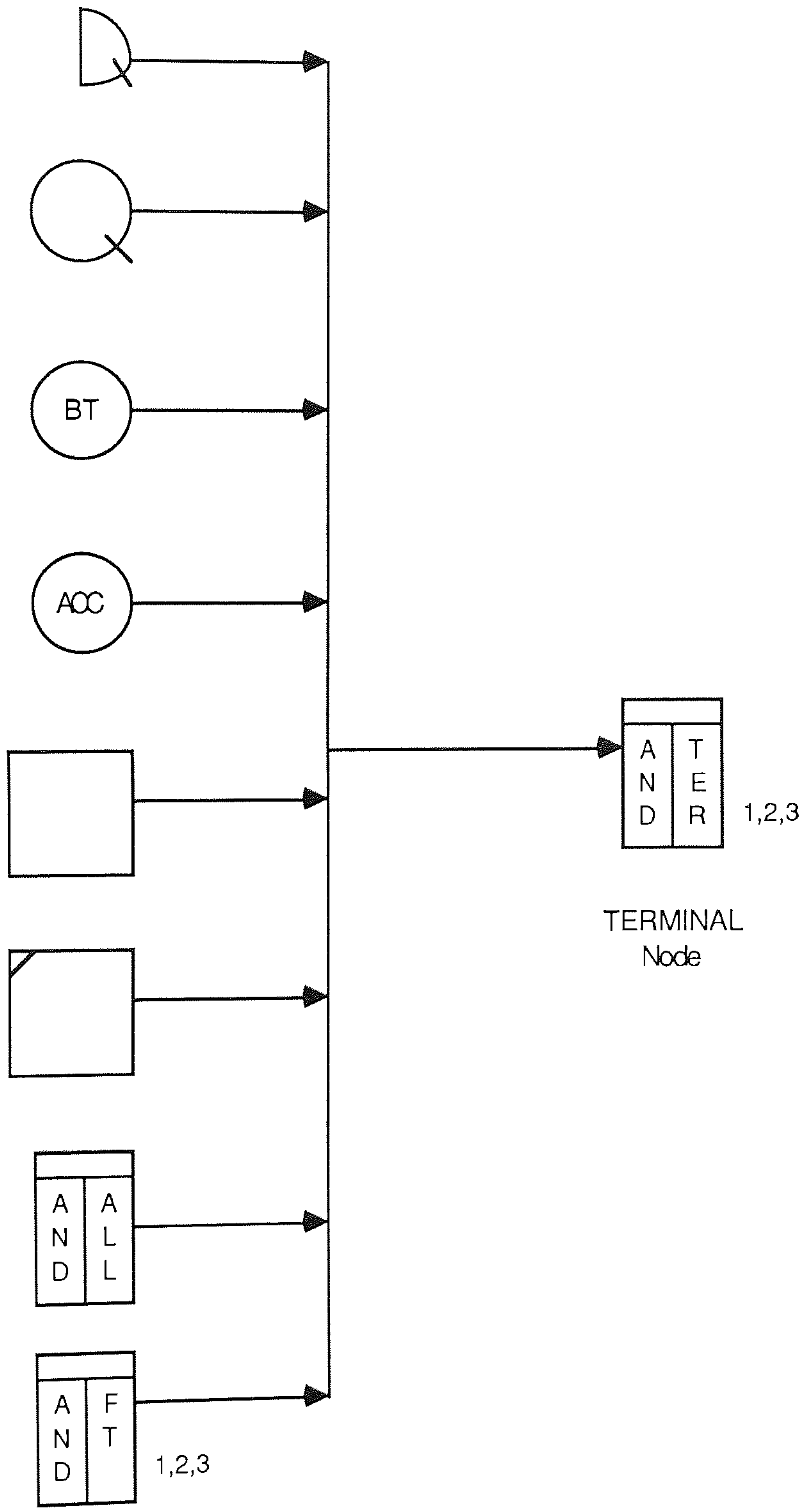


Figure (4-26)

Chapter Five

Utility Data

And

Next-Event Method Of Simulation

5.1. Introduction :

As mentioned earlier (chapter three), in this thesis the C.P.M. or Bar Chart is deemed good enough for planning at the summary level (pre-bid plan and master plan) (see sections 1.8.1 and 1.8.2). The process of planning starts by dividing the project into its components in developing the Project Breakdown Structure (PBS) chart (see section 1.7). Depending on the size of and complexity of the project, the details of PBS for the process of pre-bid and pre-construction planning may be confined to the workpackage and functional element level.

After drawing the summary plan (pre-bid or master plan), quantity take offs are obtained from detailed drawings, the bill of quantities and the PBS chart to define the amount of work involved in each activity. The next stage is to estimate the time and cost of each activity and work out the total time and cost of each stage of construction and for the project as a whole.

For many years, contractors relied on the unit-cost system in which overall unit cost, including the cost of labour, materials, equipment and overheads, were applied directly to the actual quantity take offs. In the last decade, as sharp price changes for all components occurred, requiring more clear comparison for control, this method is becoming increasingly rare in successful companies [12]. Nowadays, almost all successful contractors estimate new projects using separate categories and evaluations for labour, material, equipment usage and subcontractors. This method eases the application of the proposed model.

The output schedule for the master plan gives a rough guide to the time and cost targets for each stage of construction, as well as the amount of each type of resource required for achieving the construction works. The proposed model offers flexibility in modelling the cost and its accumulation. The planner can accumulate the cost of each stage separately and define the target cost of each stage. At the construction phase, each stage of the project will be monitored separately in terms of cost variations. In other case, he can accumulate the cost throughout the project, and the cost constraint at the end of each stage representing the cost target at this point for the whole work from the start of the project until the end of the current stage.

Detailed planning starts after the production of the master plan and schedule. It depends on the size of the project and its time span. Detailed construction plans can be prepared either for part of the project or for the project as a whole. At this stage in the plan, the Project Breakdown Structure (PBS) will be expanded to the required level of detail which may reach the work item level (see section 1.7).

At the start, each stage of the project shown in the master plan will be studied in isolation. The main network will be designed and drawn for each stage using the modelling elements of the technique(activity nodes, milestone nodes, and space Queue nodes) (see section 4.4). All the networks will then be linked together through their interface points to obtain a main network for the part of the project under investigation or for the project as a whole. This main network is linked to the master plan through common milestones. These have the same time and cost targets already defined in the master plan.

After drawing the main network, all activities and milestones will be arranged in a list, then the quantity of work involved in each activity will be defined using the detailed drawings, bill of quantities and PBS chart. The Space Queue nodes shown in the network will be arranged in a separate list. From the master plan and schedule, the main network and the PBS chart, the planner defines all types of resources required for the work.

After defining the policy of proceeding and deploying resources, a resource flow network for each type will be designed, using the relevant modelling elements of the technique (see section 4.5). The PBS chart is of great help throughout the process of drawing this type of network. It shows the type of work which can be achieved by the same resource crew or by the same mixture of resources.

After drawing the resource flow networks, all the Resource Queue nodes of each type of resource together with summary information on the relevant resource will be arranged in separate lists. The next step of planning is to produce cost estimates for all resources and time estimates for each activity. These are called utility data [6].

5.2. Estimating Cost :

The total cost of completing an activity and of the project as a whole includes:

- The material, labour, and equipment costs.
- The administration, supervision, and site expenses.

The first group of costs are directly related to each individual activity, they are thus classed as direct costs. The second group comprises the indirect costs, they are not related to individual activity duration, and generally vary approximately linearly with project time. For this thesis the "all-in-rate" cost is adopted to define the unit cost of each resource category. This is used as defined by the " Code Of Estimating Practice" [29], but with the following slight difference:

The cost of items related to the site supervision, administration, and other site expenses are considered separately under site overhead cost. This is because, unlike other models, the technique is able to consider overhead costs directly in the structure of the network. For details of the "all-in-rate" cost calculations, the reader can refer to the above mentioned reference and other texts [60,123].

5.2.1. All-In-Rate Material Cost :

This is the cost per unit of material in place including the unit price charged by the supplier, unloading cost, overhead cost (placing and expediting orders), expected storage cost, and the cost of double handling (if materials have to be stored off the site or far from the work location area). When the unit cost of each type of material is defined, the total cost of materials for each activity can be calculated by multiplying the required quantity (including a wastage allowances) by all-in-rate unit cost.

In the model the direct cost of completing each activity consists of fixed and variable costs. The cost of material represents the fixed cost of an activity, in a sense that this cost is not related to the activity duration.

5.2.2. All-In-Rate Labour Cost :

The rate per hour for the employment of labour depends on the type of labour and period of employment on the project. The rate can be calculated either for a specific category of labour or for a crew consisting of more than one category. The calculation goes through the following stages:

1 - Determine the number of normal working hours which an operative or crew is expected to work during a specific period or one year as required.

2 - Calculate the cost of employment during the specified period for wages, bonus allowances, sick and holiday payments and other expenses.

3 - By dividing the total cost in (2) by the number of working hours calculated in (1), the all-in-rate labour cost/hour will be obtained.

5.2.3. All-In-Rate Plant Cost :

The rate per hour of plant is dependent on the type of plant and whether it is contractor owned or hired. The calculation of the all-in-rate cost for plant items is as follows:

1 - Determine the average number of operating hours the plant is expected to work on the project during a specific period.

2 - Calculate capital, depreciation, maintenance, and operating costs for the defined period.

3 - The all-in-rate for plant cost/hour can be obtained by dividing the total cost produced in (2) by the number of operating hours calculated in (1).

After defining the cost/hour for all types of resource, it is possible to produce the cost/hour or cost/day for gangs or crews of resources made up of several skills or types of machinery and equipment. Figures (9, and 10) in the appendix show an example of the make-up and cost/day for the machinery and labour resources used in the case study in this work. Some types of equipment have to be shared by several trades and the model is able to determine the cost of this type of equipment using the logic of the BETWEEN node (see section 4.4.4). Figure(42-apendix) shows an example of this type of equipment and their cost/day.

5.2.4. Overhead Cost :

This includes the wages and other benefits paid to the site administrative, management, supervisory, and technical staff. The cost of site services such as : water, electricity, telephone charges, canteen and travelling to and from the site expenses are also included. The cost of these items is very low at the beginning of the work where the level of activity is relatively low. The changes in this type of cost can be represented in the model using different BETWEEN nodes. Figure (42, appendix) shows site overhead costs for different parts of the case study.

5.3. Estimating Time Durations :

The technique is able to consider directly in its structure only the part of the uncertainty due to variation in the time duration of an activity (see section 1.6.1). The effects of external interference on activity time duration are considered indirectly. When defining the target date of the project in the pre-bid and master plan, 10-20% of the agreed contract duration is considered as spare or contingency time to compensate for unforeseen conditions and for the impact of those external factors (see section 1.6.2).

The process of estimating the time duration of each activity is quite different from that of C.P.M. In C.P.M or any other techniques. In C.P.M, the estimate is based on a normal level of resourcing for each activity without considering that the same types of activity are carried out by the same crew or resource. With the current technique, the same types of activity are grouped together to make a production line for a specific type of resource. This is represented by the resource flow network of this specific resource.

The process of estimating the time duration of each activity starts by defining the normal size of the crew or gang which is supposed to achieve the activities on the same production line. This normal size is based on company practice, and the planner's experience and judgement. It depends on the amount of work involved in each activity. The size of the crew matches what is called a normal level of resourcing for some activity, for others the size may be less or more than the normal level.

The aim of this arrangement is to provide a continuity of work for each type of resource. It should be noted here that the technique allows changing the size of the resource crew by using the Resource Queue and SINK nodes (see section 4.5). When the structure of each gang and crew is designed and the size of the crew is defined at each stage of its resource flow network, the planner estimates the productivity of each resource gang or crew.

His estimates are based on normal company practice, past records of the same structure and size of the crew, and on his experience with the same types of resource. Productivity is the amount of work which can be achieved by a worker or a crew per unit of time. The value of productivity of a specific resource is affected by several random variables (see section 1.6.1).

The planner produces a range of productivity figures to represent its variability. Relying on the productivity estimates of each type of resource and on the quantity of work involved in each activity, the planner produces an estimate for the time duration of each activity. Throughout the process of estimating, the planner takes into account the location of the work, the difficulties involved, the nature of the crew make up, and other factors affecting the time duration of an activity. It depends on his judgement of the situation. For some activities he may produce a one point estimate if the amount of work involved is small and the variability is expected to be so small that it can be neglected. For other activities, the variability may be expected to be large, and in this case, he may produce a range of time estimates for their duration.

Four types of probability distribution are built into the structure of the developed software in addition to a constant value to provide flexibility in representing activity time duration. They are:

1. Uniform Distribution :

In some cases, the type and amount of work, and the expected work environment of specific activities makes it difficult for the planner to estimate the most probable value of the time duration. In this case, it is easier for him to estimate a minimum value which coincides with very favourable conditions and a maximum value which matches the worst scenario. The Uniform distribution fits this case.

2. Beta Distribution :

Usually the first time estimate that naturally comes to the mind of the estimator when considering variability is an approximation of the mode of the distribution of possible times. The next are the extreme values (minimum and maximum). The estimator, in many cases, may have little confidence in the occurrence of good conditions, so his estimate of the minimum value falls closer than the maximum value to the most likely point.

In this case the Beta distribution is a good representation of the probability of occurrence of particular durations. The most important feature of this distribution is its ability to represent any skewed sample. In the software, the shape of the Beta distribution is defined by relying on these three point estimates, and by solving the resulting cubic function to define the mean and standard deviation. This eliminates the errors resulting from PERT approximation.

3. Triangular Distribution :

This is used for the same situation mentioned in the previous paragraph, but where the planner feels that the variability between the three point estimates is likely to be linear.

4. Bounded Normal Distribution :

In some cases, the planner feels that the extreme values fall at equal distance from the mean. In the software, the Normal distribution is bounded at the extreme values which are considered at three standard deviations from the mean.

The sampling procedures from each of these distributions are demonstrated and explained in almost every text written on simulation. The interested reader may refer to the following texts [1,52,77,92,99,102,116].

The facility of representing time as a fixed value is provided in order to represent the time duration of an activity which does not vary, such as the hardening period of concrete (i.e. curing time) or the primary settlement period of the foundation layer in road construction. It is also useful for those activities for which the duration is almost certain. For example, inspection activity, testing activity (especially in road construction).. etc.

5.4. Preparing The Data For Input And Analysis:

Three types of list (showing data on the network structure, resources, and time and cost estimates) are designed to facilitate the process of software development. They are used to design all parts of the computer program, for validating the internal logic of the computer simulation module and the output of its analysis. They also serve the purpose of inputting the required data to the developed software. They are:

-The Activity and Milestone list.

-The Space Queue nodes list.

-The Resource list.

5.4.1. The Activity And Milestone List :

This list contains information on the sequencing logic for each activity, milestone, and on the start and terminal nodes, together with resource information, time, and cost. Figure(5-1) shows the data for the activity represented by a COMBINATION node. The right hand side of this record displays the information which is generated during simulation.

The data required for a NORMAL node are shown on figure(5-2), it is clear that this type of node can not be preceded by a Resource Queue node or Space Queue node. The starting node (INITIAL-AND) information is shown in figure (5-3). The time duration of this node is zero. It can have different times to initiate the network, also it has an initial cost which represents the cost of moving to the site. The node is always on the critical path. So its criticality index equals unity. Its starting time is fixed because it initiates the start of the work. Figure (5-4) displays the record of AND-ALL and AND-FILTER,1,2,3 milestone nodes. Their time and cost equal zero, and they can not be preceded by Resource Queue nodes.

The data of AND-TERMINAL,1,2,3 nodes are displayed in figure (5-5). Again these nodes can not be preceded by Resource Queue nodes, and obviously have no succeeding nodes. They are always on the critical path, so their criticality index equals unity. Their cost and time duration equal zero.

5.4.2. Space Queue Nodes List :

This list contains data on the Space Queue and Function nodes in the main network. Figure (5-6) shows the record of the Space Queue node. Each Space Queue node is preceded and succeeded by only one node (either an activity node or a milestone node). The record can be used for a Space Queue node with or without a cost function. At each iteration, the idle time observed can be recorded together with the cumulative cost passed to the node in the relevant field in the record.

The data for the BETWEEN node are shown on figure (5-7), where the time period and total cost incurred in each iteration can be recorded on this record. Figure (5-8) displays information on the ACCUMULATOR node. This node is succeeded by only one node, and can be preceded by several nodes, each passes a cumulative cost to the ACCUMULATOR node. At the end of the iteration the sum of the costs passed to it will be passed to its succeeding node.

Activity Des.	Preceding Nodes			Time & Cost Parameters		Iter-No	1	2	3
	All types Except R.Q	R.Q.Nodes		Variable Cost/Time		Cum-cost of Pre-nodes			
	Label	Label	No Of Units	Fixed Cost		Starting Time			
				Type Of Duration		Duration			
				Constant		Total Variable Cost			
	Succeeding Nodes			Most likely or Mean value		Total cost Of Activity			
	All Types Except R,Q	R.Q.Nodes		Minimum Value		Total cost to be transfered			
	Label	Label	No of Units	Maximum Value		Criticality index			

Figure (5-1)- COMBINATION Node Data Record.

Activity Des.	Preceding Nodes			Time & Cost Parameters		Iter-No	1	2	3
	All types Except R.Q	R.Q.Nodes		Fixed Cost		Cum-cost of Pre-nodes			
	Label	Label	No of units	Type Of Duration		Starting Time			
				Constant		Duration			
				Most likely or Mean value					
	Succeeding Nodes			Minimum Value					
	All Types Except R,Q	R.Q.Nodes		Maximum Value		Total cost to be transfered			
	Label	Label	No of Units			Criticality index			

Figure (5-2)-NORMAL Node Data Record.

Activity Des.	Preceding Nodes			Time & Cost Parameters		Iter-No	1	2	3
	All types Except R.Q	R.Q.Nodes		Initial Time					
	Label	Label	No of units	Initial Cost					
				Duration = 0					
	Succeeding Nodes								
	All Types Except R,Q	R.Q.Nodes							
	Label	Label	No of Units			Criticality Index = 1			

Figure (5-3)- INITIAL-AND Node Data Record.

Activity Des.	Preceding Nodes			Time & Cost Parameters		Iter-No	1	2	3
	All types Except R.Q	R.Q.Nodes		Cost= 0	0	Cum-Cost Of Pre-Nodes			
	Label	Label	No of units	Time Duration= 0	0	Realization Time			
				Cost Constraint		Cost Constraint-ind			
				Time Constraint		Time Constraint-ind			
	Succeeding Nodes					Criticality index			
	All Types Except R,Q	R.Q.Nodes							
	Label	Label	No of Units			Criticality Index = 1			

Figure (5-4)-AND-ALL, and AND-FILTER-1,2,3 Nodes Data Record

Activity Des.	Preceding Nodes			Time & Cost Parameters		Iter-No	1	2	3
	All types Except R.Q	R.Q.Nodes		Cost = 0	0	Realization Time			
	Label	Label	No of units	Time Duration = 0	0	Cum-Net cost of pre-nodes			
				Time Constraint		Total Idle Time-cost			
				Cost Constraint		Time Constraint-ind			
	Succeeding Nodes					Net Cost Constraint-ind			
	All Types Except R,Q	R.Q.Nodes				Total cost Constraint-ind			
	Label	Label	No of Units			Criticality index			

Figure (5-5)-AND_TERMINAL-1,2,3 nodes Data Record

Node-Des	Pre-Node	Succ-Node	Iteration-No	1	2	3
			Cum-Cost Carried Forward			
			Idle Time			

Figure (5-6)-Space Queue Node Data Record.

Node-Des	Pre-Node	Succ-Node	Cost/Time	Iteration-No	1	2	3
				Time Duration			
				Total Cost			

Figure (5-7)-BETWEEN Node Data Record.

Node-Des	Succ-Node	Pre-Nodes		Iteration Number	1	2	3
		Label	Cost Carried Forward				
		Total Cost					

Figure (5-8)- ACCUMULATOR Node Data Record.

5.4.3 Resource Lists :

The data regarding each type of resource are arranged in a separate list. This list contains information on all Resource Queue nodes and SINK nodes in the resource flow network, and summary information regarding the resource itself. Figure (5-9) shows the data for a Resource Queue node with Single Successor.

The node is preceded and succeeded only by one node. At each iteration the idle time recorded by this node is multiplied by the number of resource units (number of gangs or crews) to obtain the idle resource time unit (such as X gang.days). The result is recorded in the record in the relevant field. The data for a Resource Queue node with Multi-Successor are shown on figure (5-10). This node is preceded by only one node and succeeded by several nodes each requiring a different number of resource units.

At each iteration, if any number of resource units is left idle in this node, the idle time will be multiplied by this number to obtain a sub-idle resource time unit. When all the activities succeeding this node are achieved, these sub-idle resource time unit will be accumulated to obtain a total idle resource.time unit. Figure (5-11) shows the data for a SINK node. At each iteration, the time at which the number of resource units is released is recorded on the record. Finally, figure (5-12) shows the summary data on the resource. It displays the cost of the resource unit/unit of time which is estimated or worked out before the start of the simulation (see section 5.2).

At each iteration, for each resource, all the idle time recorded by all its Resource Queue nodes will be accumulated. The result will be recorded in the record of figure (5-12) to get statistics on this parameter. The total idle time will be multiplied by the resource cost/time unit to obtain the cost of the idle time of this resource. This will be recorded in the record to be accumulated with the cost of the idle time of other resources and passed to the TERMINAL node.

Node-Des	Pre-Node	Succ-Node	No Of Units	Iteration-No	1	2	3
				Idle Resource Unit. time unit			

Figure (5-9)-Resource Queue Node(Single Successor) Data Record

Node-Des	Pre-Node	Succ-Nodes		Iteration-No	1	2	3
		Label	No.of.units				
				Sub-Idle Res.T			
				Total idle time			

Figure (5-10)-Resource Queue Node (with multi-Successor) Data Record

Node-Des	Pre-Node	No.Of.Units	Iteration-No	1	2	3

Figure (5-11)-SINK Node Data Record.

Resource-Des	Cost R.unit/T.unit	Iteration-No	1	2	3
		Total idle Resource Unit. time unit			
		Total idle Time Cost			

Figure (5-12)-Summary Data On The Resource Idle Time And Its Cost

5.5. Next-Event Method Of Simulation :

The objective of designing the main network and resource flow networks for the project is to examine the interaction between different resources and activities, determine idleness of productive resources, locate bottlenecks, balance the level of resourcing to eliminate idleness and produce a workable plan and schedule. In order to achieve this, the flow of resources through the modelled queuing system must be studied in a manner that simulates the movement of the real world production resources.

Since the technique is able to consider the variability in activity time duration, Monte-Carlo simulation can be used to move the flow of resources through their production lines (resource flow networks) and advance them from their idle states (Resource Queue nodes) to their active states (activity nodes). The period of time during which the resource stays active (activity duration) can be defined using pseudo random numbers. These are used to select variants from probability distributions (see section 5.3) that represent the randomness of the activity durations. If the activity duration is deterministic (i.e. constant), a simple simulation can be performed without the need for using pseudo random numbers and sampling processes.

In both cases (constant or random duration), the movement of resources takes place at discrete points in time. That is, the simulation of resource activity (e.g. excavation for column foundation) is defined in terms of its starting event and its end event. The resource is captured between the start and the end of the activity. The start of the queuing system represented by the network is related to the movement of resources at fixed points in time (i.e. when resource become active). Also when the resource is delayed at the Resource Queue node, and when the work location stays idle awaiting the availability of resources at the Space Queue node, all are discrete events along a line representing the passage of time.

Because of the discrete nature of the flow of resources and the state of work locations in the network model, the procedure for simulating this system is called a discrete system simulation [58,52,92,99,116].

In this system, the state of the modelled system is reviewed at regular time intervals, where the changes in the system are recorded. Depending on the nature of the modelled system, the simulation process stops after a specific amount of time or when pre-defined conditions (such as a certain amount of production) are met. The most important element of the discrete system simulation is the simulation clock. There are two techniques for handling the simulation time:

- The time slicing method.
- The Next-Event method.

In the slicing method, the simulation clock is advanced in even or equal time steps (every one or two units). After each step, the system is reviewed to see if its state has changed since previous step. This method is acceptable if the change in the system occurs regularly in a uniform way. However, the state of the current modelled system changes at irregular intervals of time. On any day, many activities may start or finish, followed by several days of no major change. The method in this case is inefficient.

In the Next-Event method the advance of the simulation clock is based on the scanning of the start and end event times of the activities and of other nodes in the system as scheduled during the simulation.

The advantages of this method are that, first the time increment automatically adjusts to periods of high and low activity during the simulation. This avoids wasteful and unnecessary checking of the state of the system. Secondly, it makes clear when significant events have occurred during the simulation. This method is used to simulate the CYCLONE network.

This section introduces a set of algorithms based on the Next-Event method to simulate the modelled system, to balance the level of resourcing and to obtain a schedule for project activities and resources. The readers who are not familiar with this method are referred to Halpin and Woodhead [58] who give a full account of the technicality of this method through a hand simulation of the CYCLONE network.

The use of this method in a hand simulation requires two types of list: An Event list and a Chronological list. The Event list is used to schedule the events of all nodes in the system. The Chronological list is used to move the scheduled nodes from the Event list to increment the time and advance the simulation clock.

This section introduces the simulation algorithms as they are designed for computer simulation. In these algorithms, there is no need for the chronological list, because the simulation clock will be advanced by relying only on the Event list. The simulation algorithms of the CYCLONE system [58] consist of two major routines: a generation phase and an advance phase routine. For the current model which has more logical elements and nodes, and where the network is not cyclic or closed, these two routines are not enough. Therefore, a third routine is designed to suit the requirement of the model.

Throughout the process of simulation, the records of all types of nodes (see figures 5-1 to 5-12) are used to obtain the utility data of each node and to store the relevant output data produced by simulation. The structure of the Event list used for simulating the system is shown on figure (5-13). In this list the first three columns are self-explanatory, the fourth column (ST) is used to store the Start Event Time of any node, and the fifth column (DUR) is for storing the duration of an activity or for calculating the idle time recorded by any Resource Queue node or Space Queue node. The sixth column is to store the End Event Time (E.E.T) of any node.

Finally, the last column is used only with the Resource Queue nodes to show the number of resource units available at these nodes. The process of simulation moves resources and schedules the start and the end of each node by observing the logical constraints on the sequencing of activities and nodes. The simulation algorithms of the model consist of three major routines:

1. Generation Phase Routine :

It is designed to schedule the end events of the Resource Queue nodes, Space Queue nodes, and Function nodes. Also to schedule the start event of activity, milestone and terminal nodes. Figures (5-14) to (5-19) show the structure of the algorithms of this routine.

2. Compilation Phase :

This is designed to schedule the end events of an activity, milestone and TERMINAL nodes, and the start events of Resource Queue , Space Queue and Function nodes. Figures (5-20) and (5-21) demonstrate the process of its algorithms.

3. Advance Phase Routine :

Figure (5-22) shows the structure of its algorithm. Its function is to advance the simulation clock(TNOW) to the minimum value of E.E.T entry in the Event list.

These routines are used continuously throughout each iteration. The frequency of using them depends on the size and complexity of the network. Another routine, the "criticality index routine" (see figure 5-23) is designed to define the critical path or paths at the end of each iteration.

At the end of the simulation experiment (i.e. after finishing the required number of iterations), statistical analysis will be conducted on the simulation output. Minimum, maximum, mean and standard deviation values are defined for each parameter and displayed on the record of each node (see figures 5-1 to 5-12). This information will be introduced in detail in the next chapter when discussing the structure of the developed software.

SEQ	Node Number	Node Type	Starting Time(ST)	Duration DUR	End Event Time(E.E.T)	No.Of Units
1						
2						
3						
4						
5						
6						
7						
8						
9						

Figure (5-13)- The Structure Of The Event List.

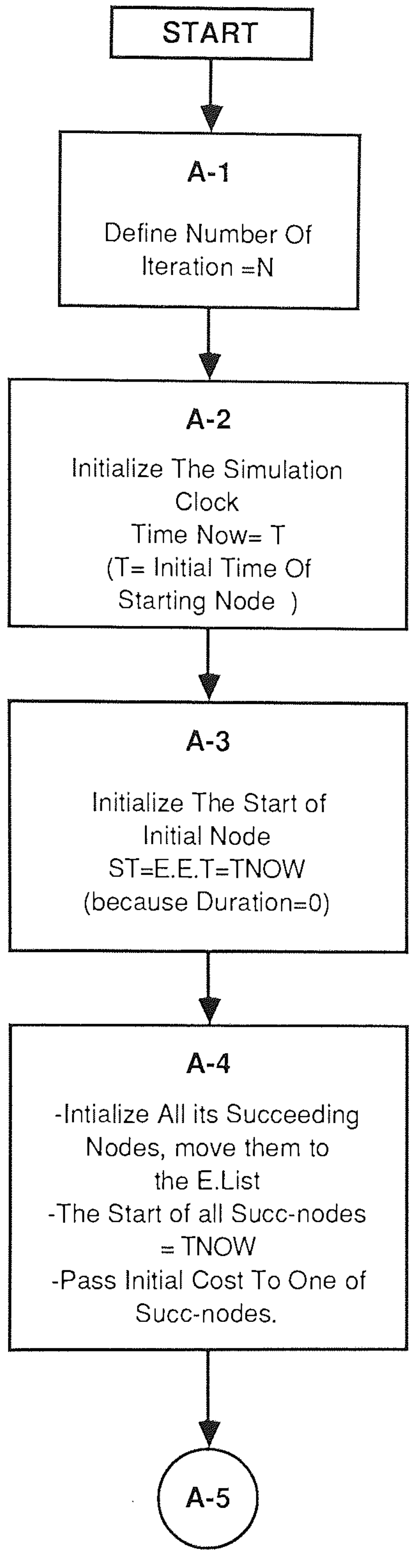


Figure (5-14)-Generation Phase.

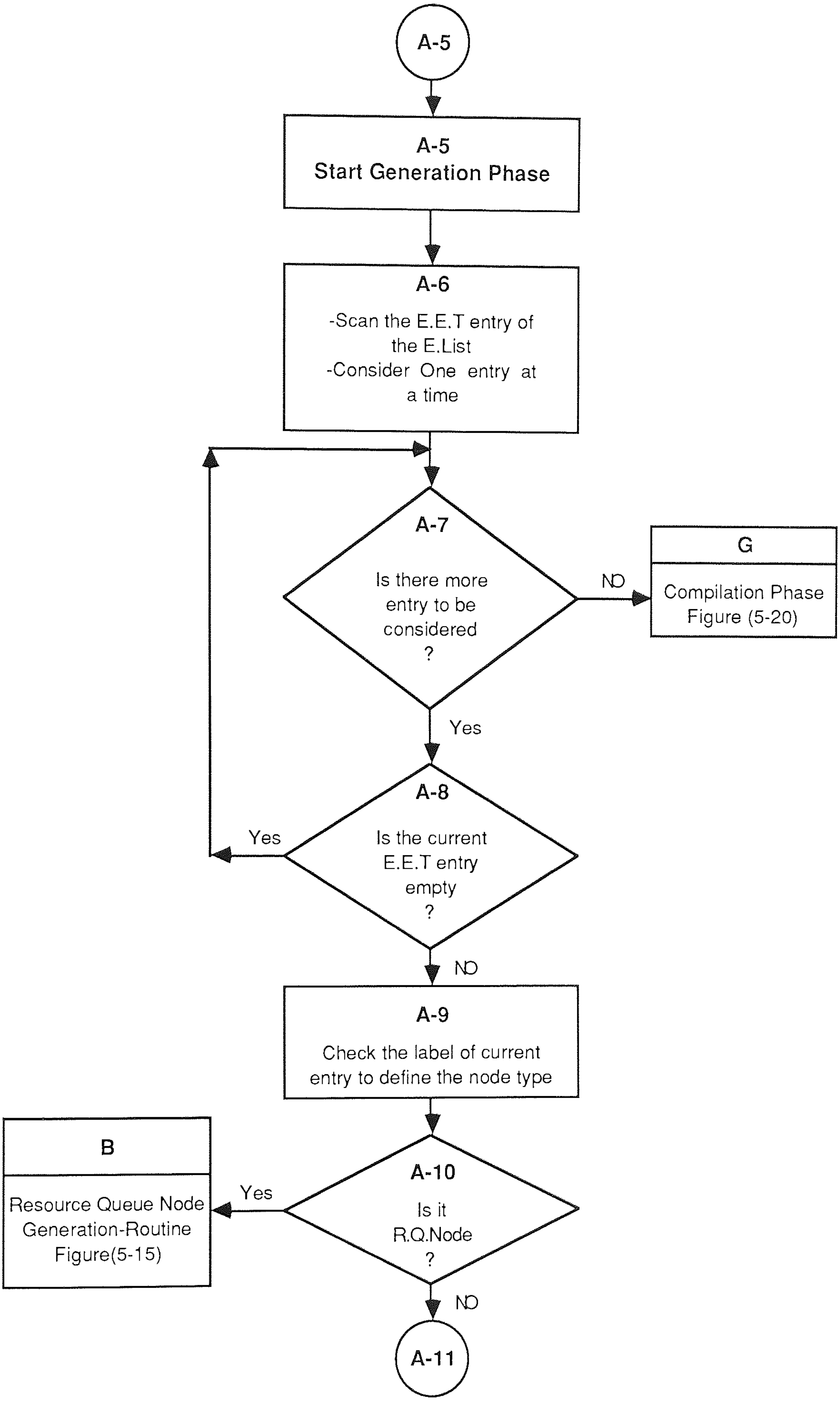


Figure (5-14)-Continued.

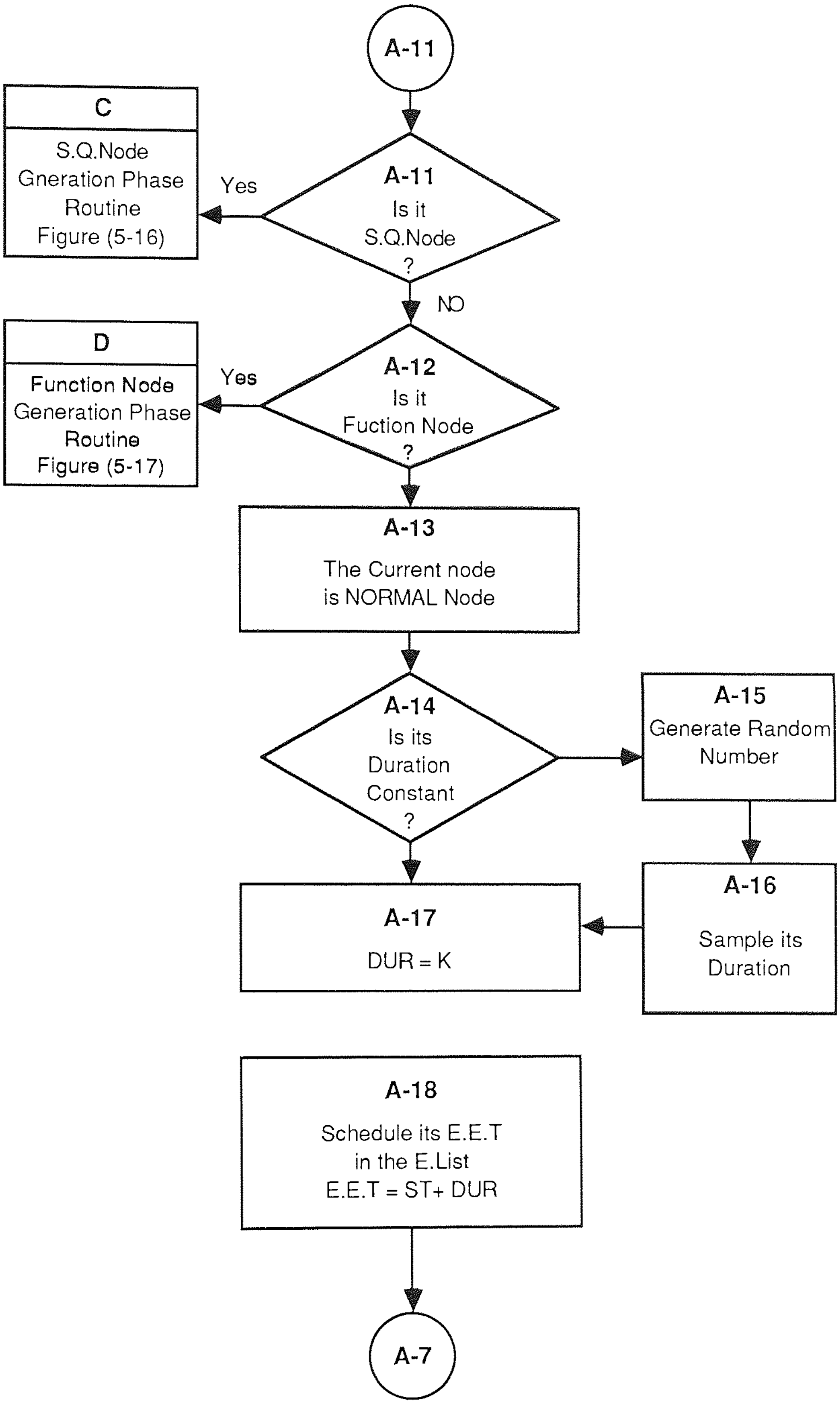


Figure (5-14)- Continued.

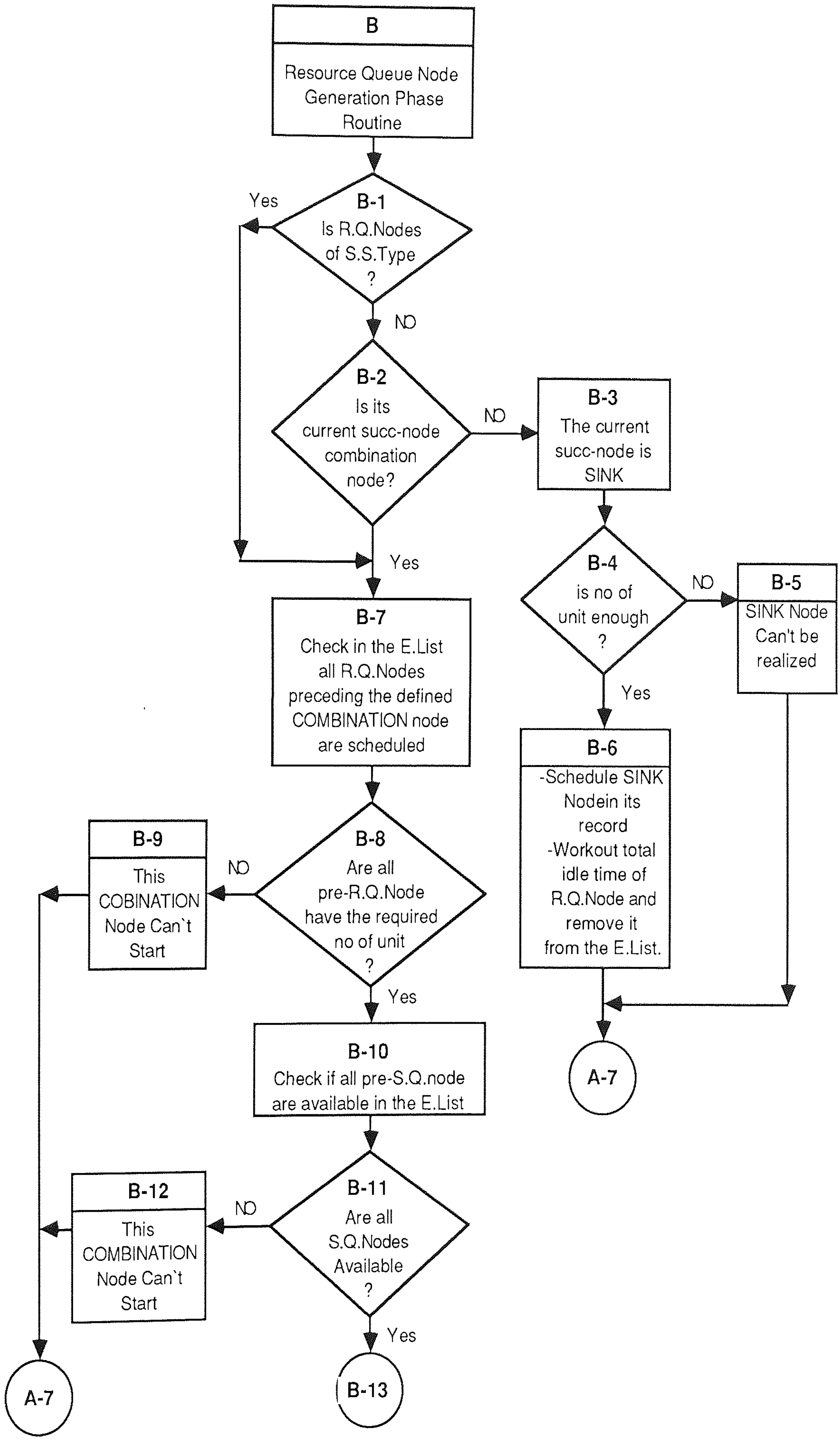


Figure (5-15)-Resource Queue Node Generation Phase Routine

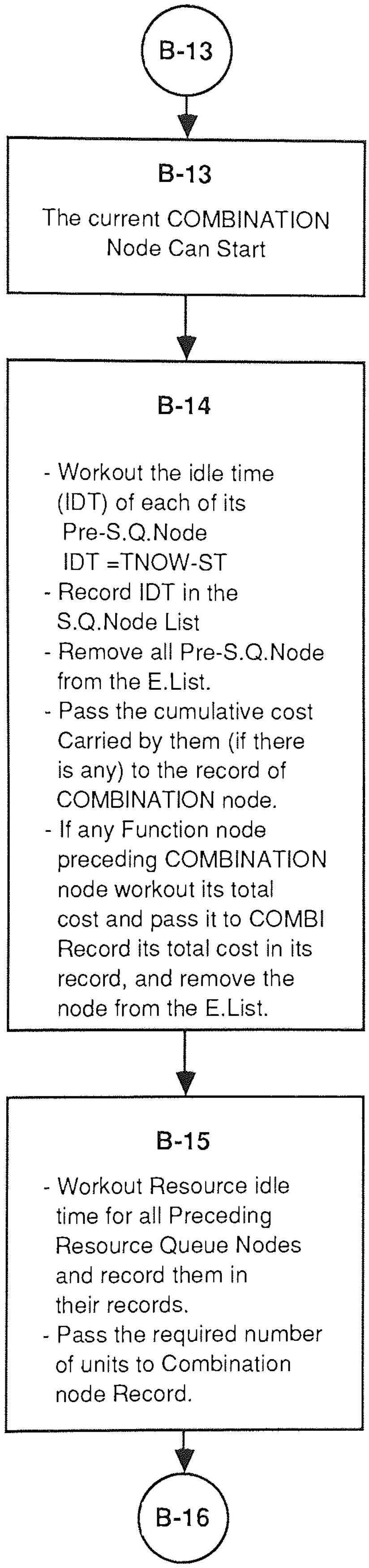


Figure (5-15)- Continued.

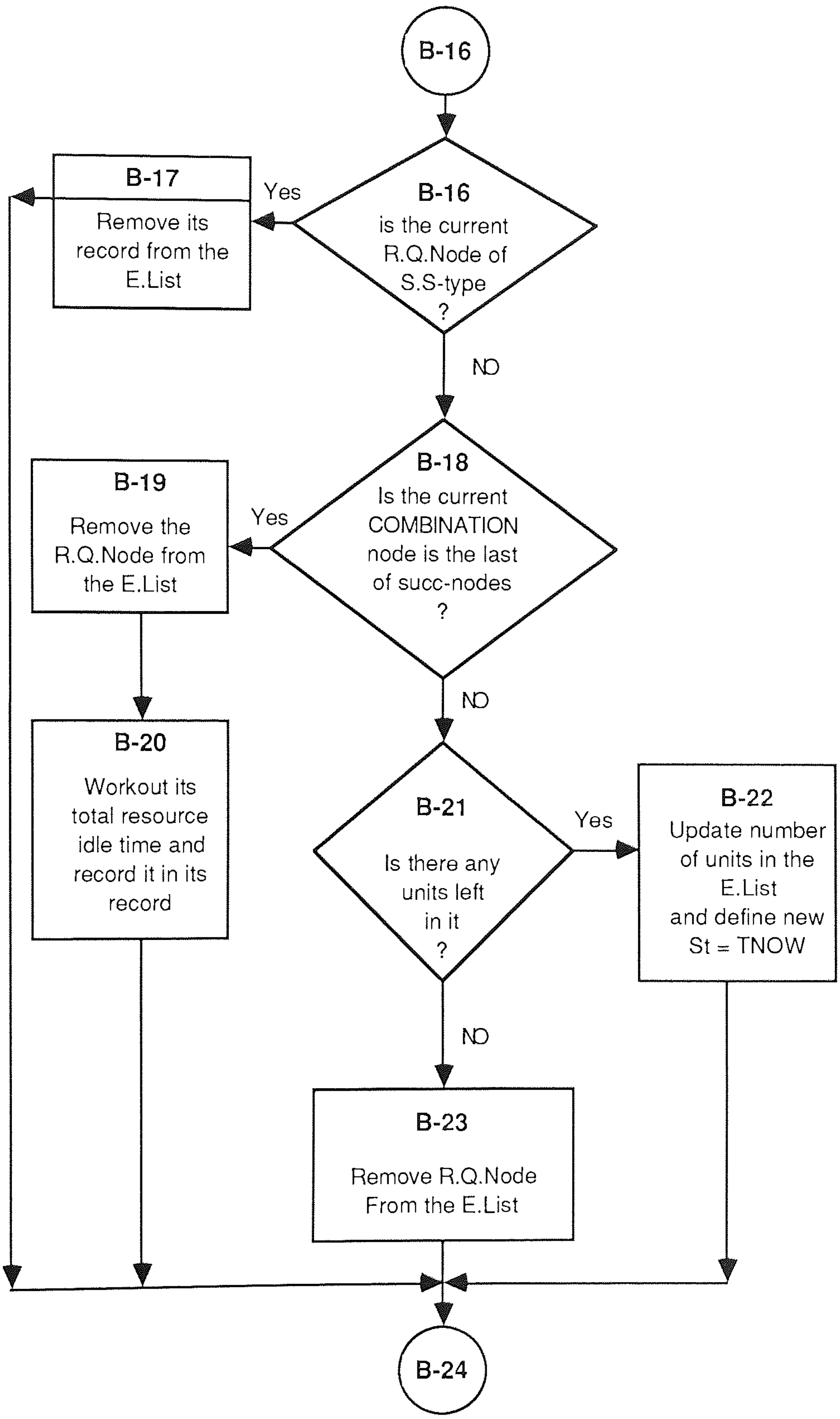


Figure (5-15)-Continued.

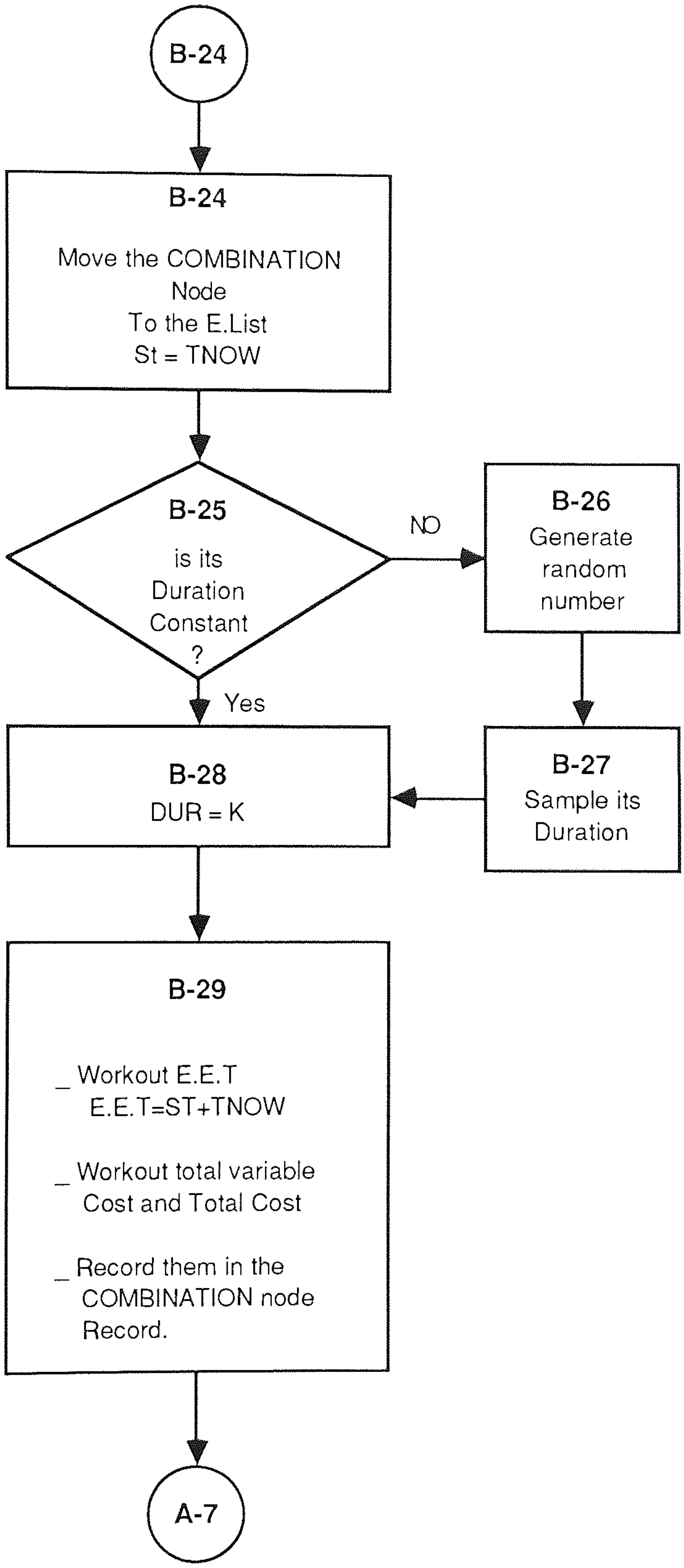


Figure (5-15)- Continued.

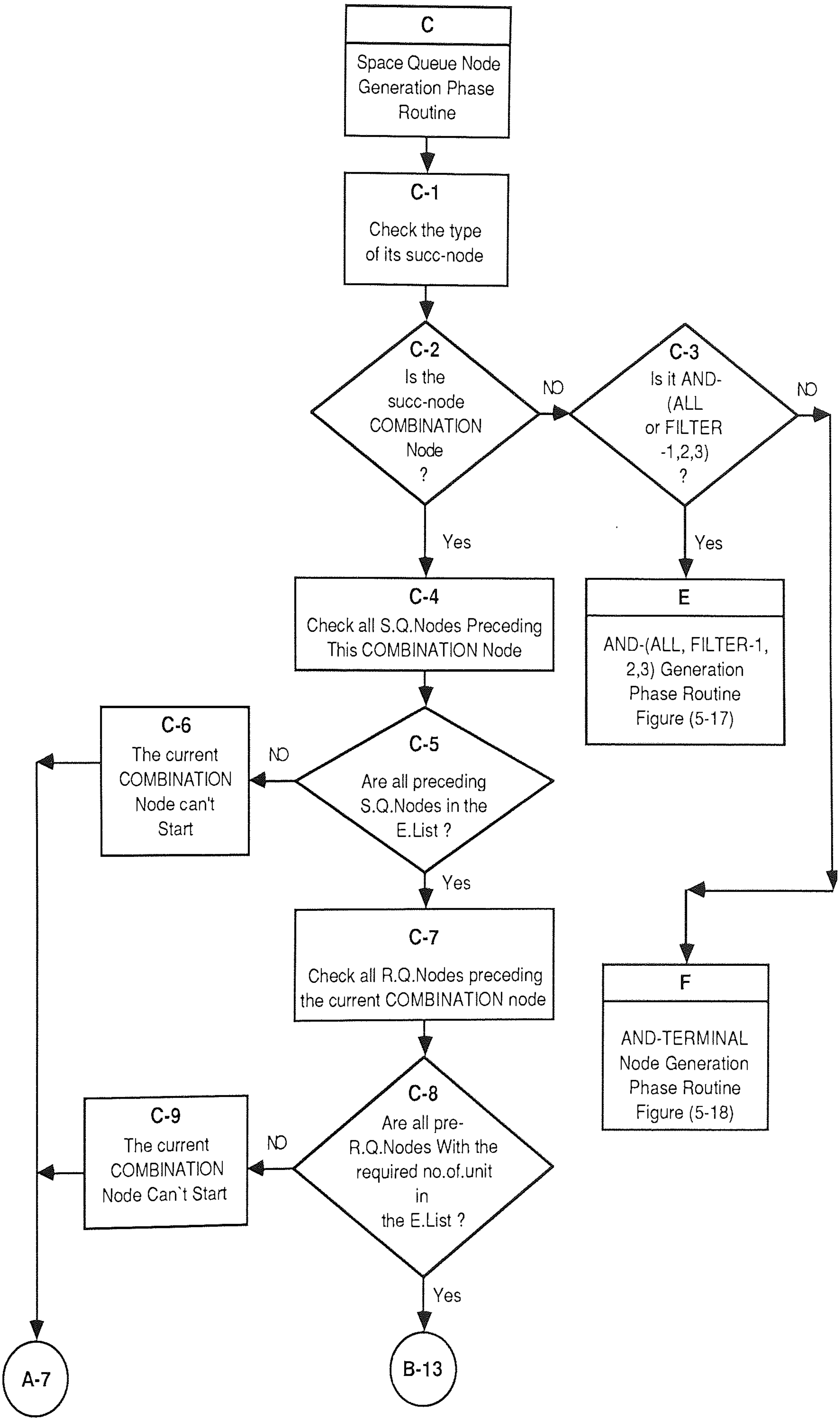


Figure (5-16)-Space Queue Node Gen eration Phase Routine

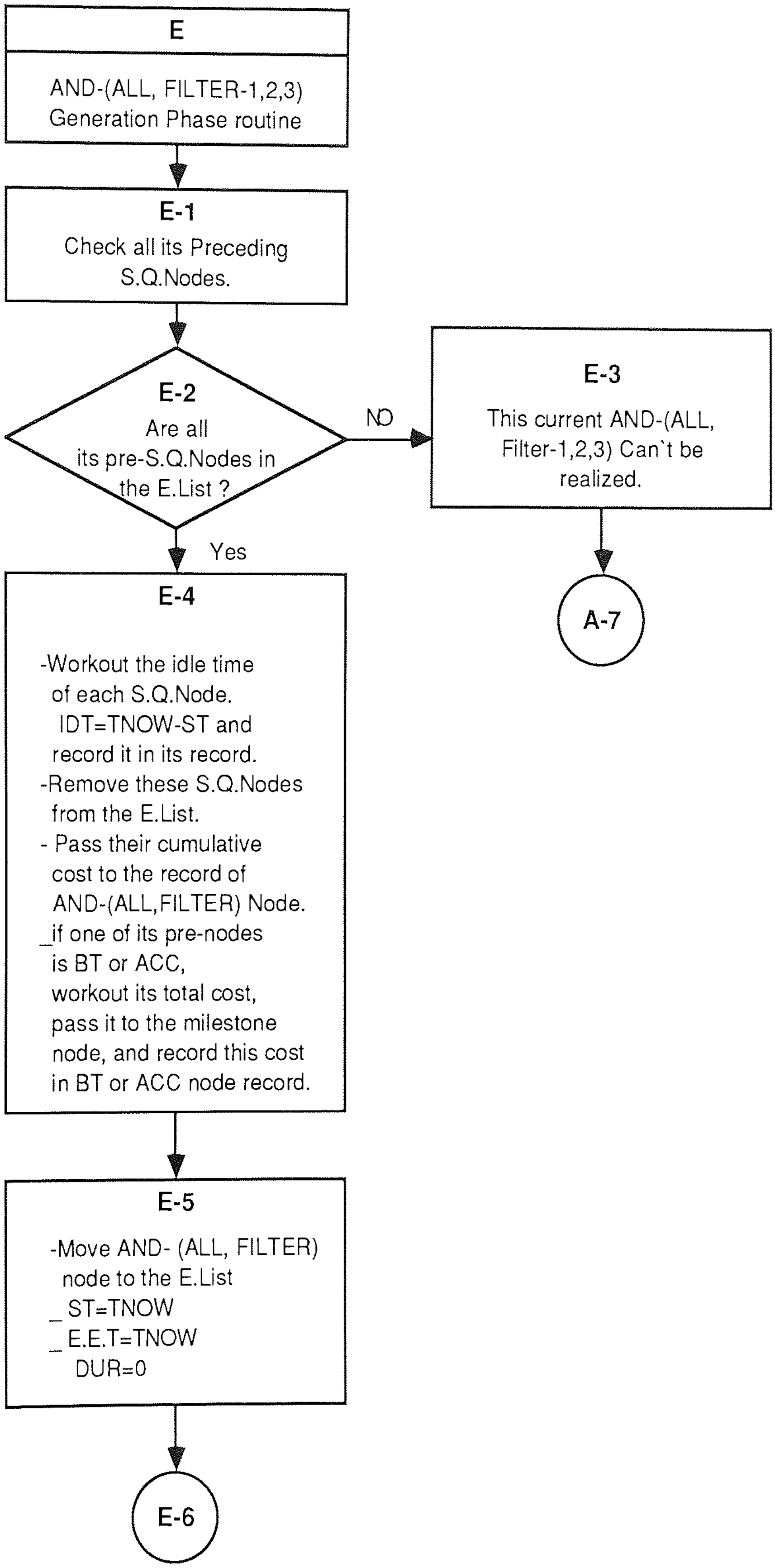


Figure (5-17)- AND-(ALL, FILTER-1, 2,3) Generation Phase Routine

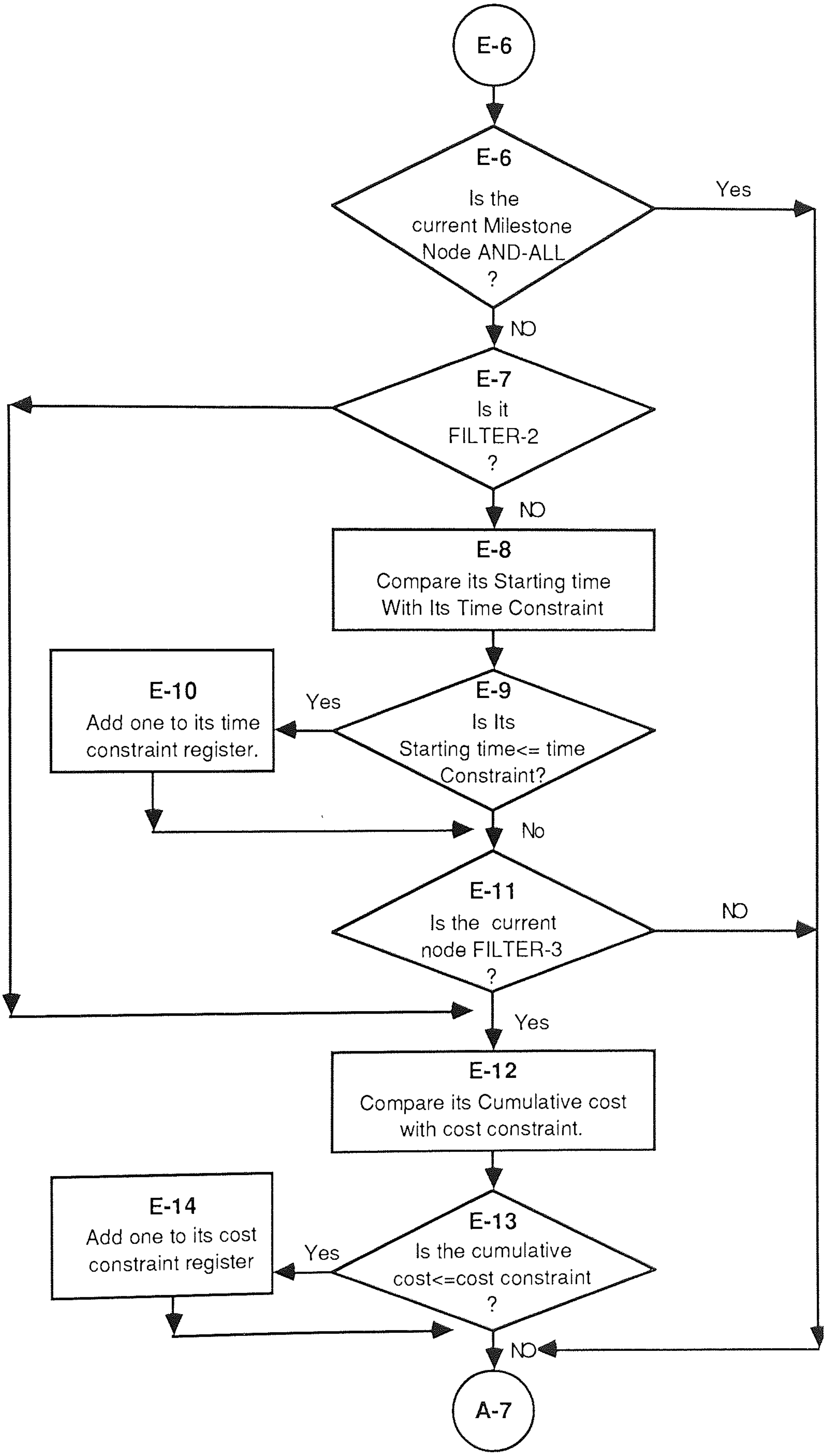


Figure (5-17)- Continued.

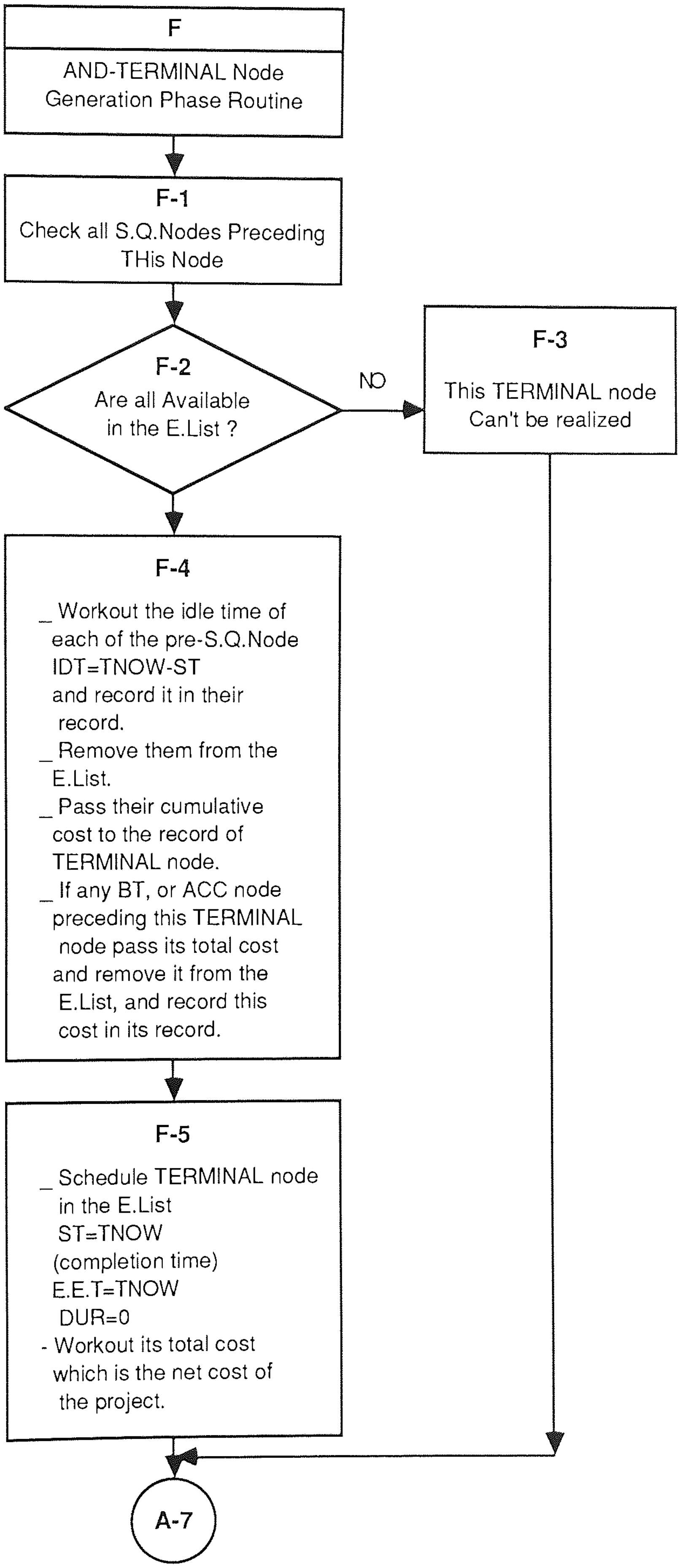


Figure (5-18)-AND-TERMINAL Node Generation Phase Routine.

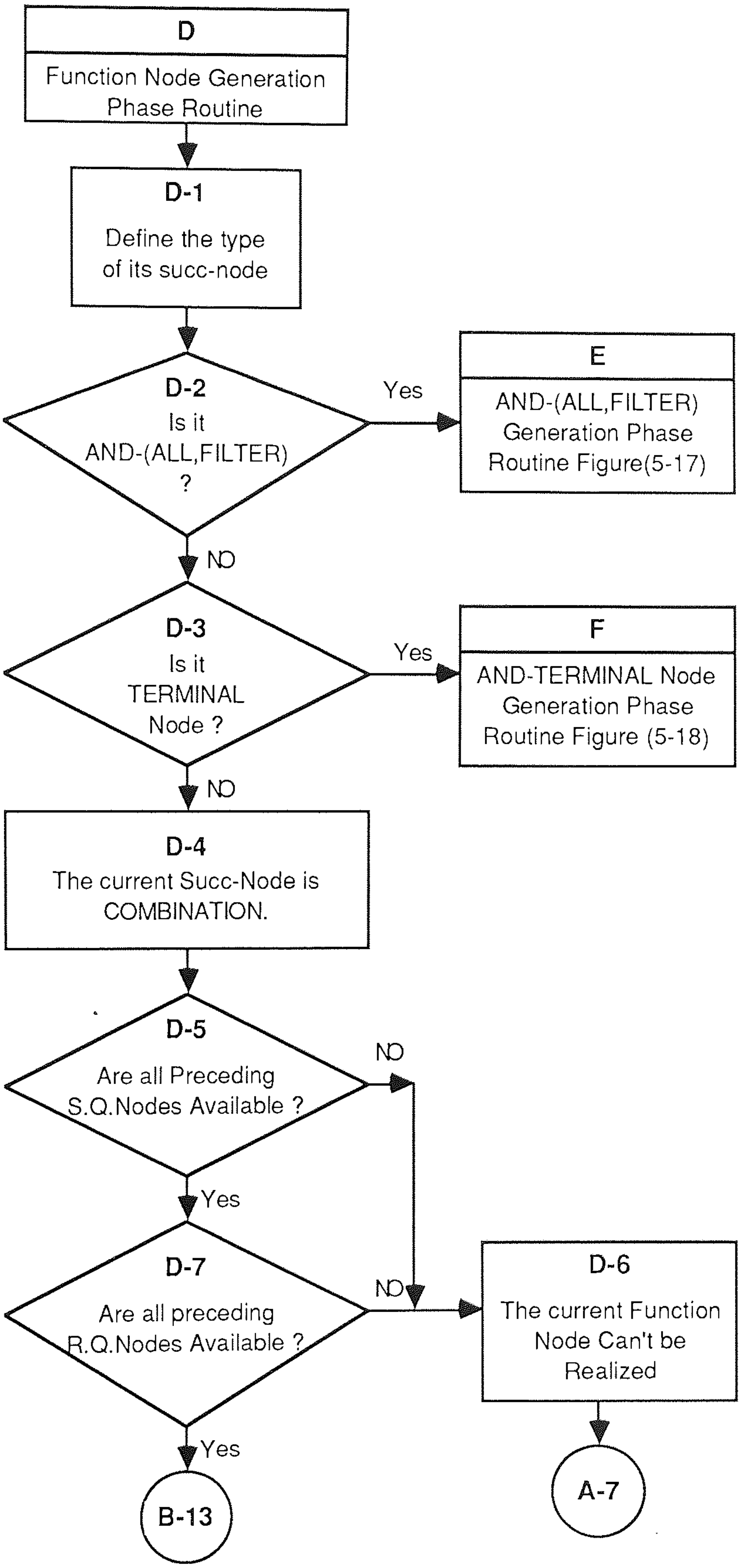


Figure (5-19)- Function Node Generation Phase Routine.

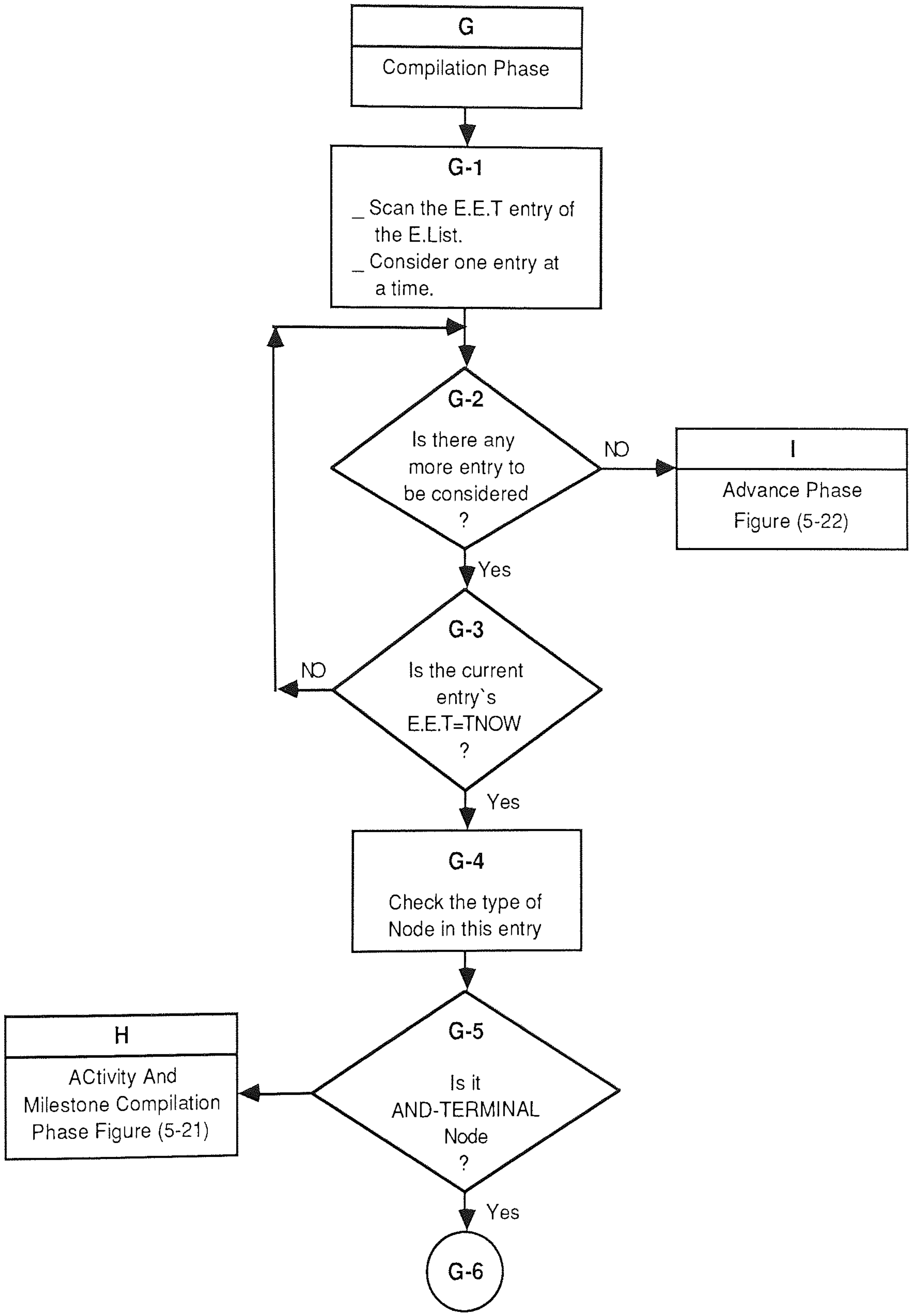


Figure (5-20)- Compilation Phase.

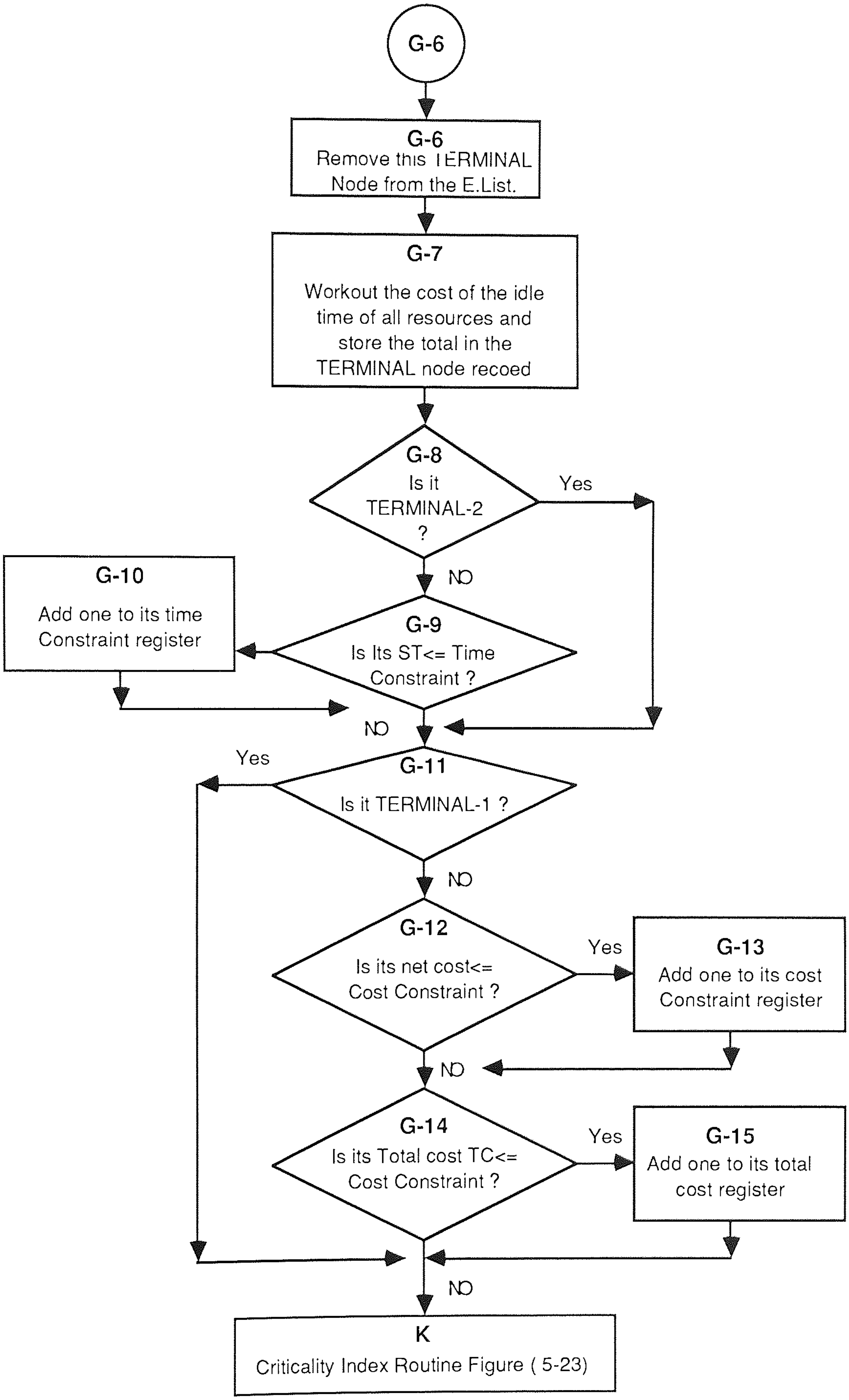


Figure (5-20)- Continued.

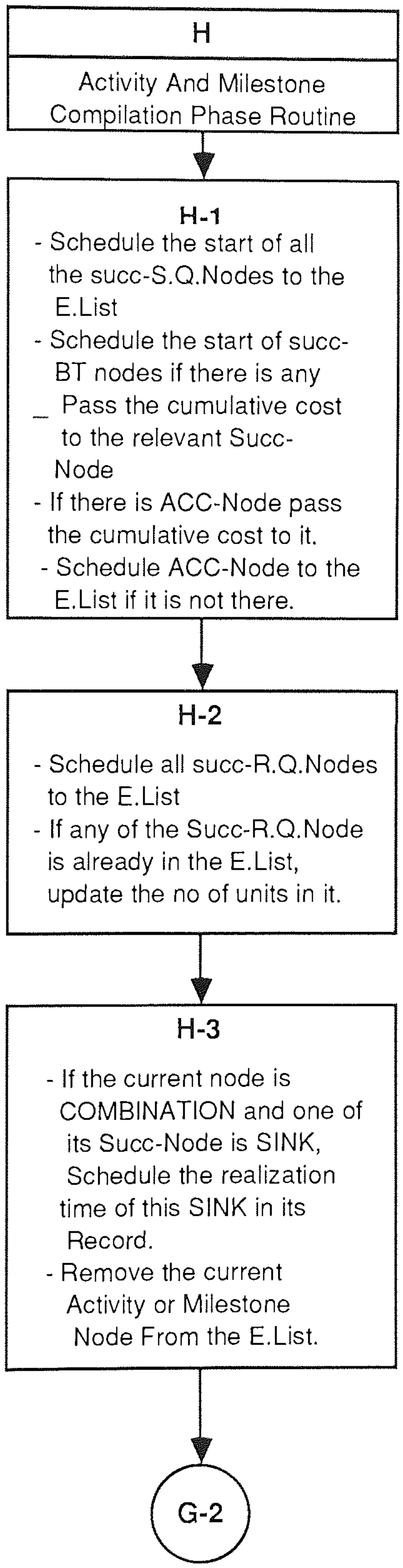


Figure (5-21)-Activity And Milesto ne Compilation Phase Routine.

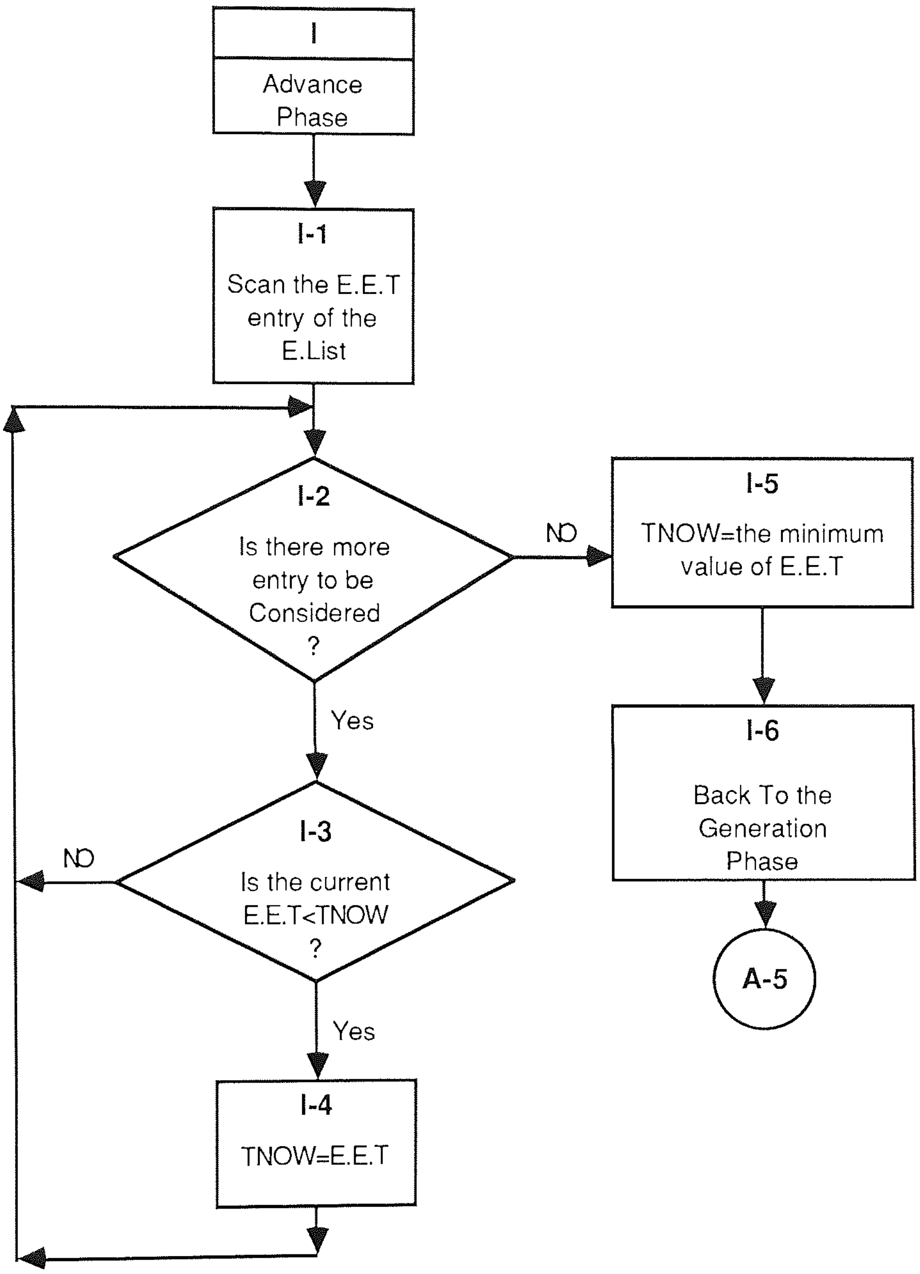


Figure (5-22)-Advance Phase Routine.

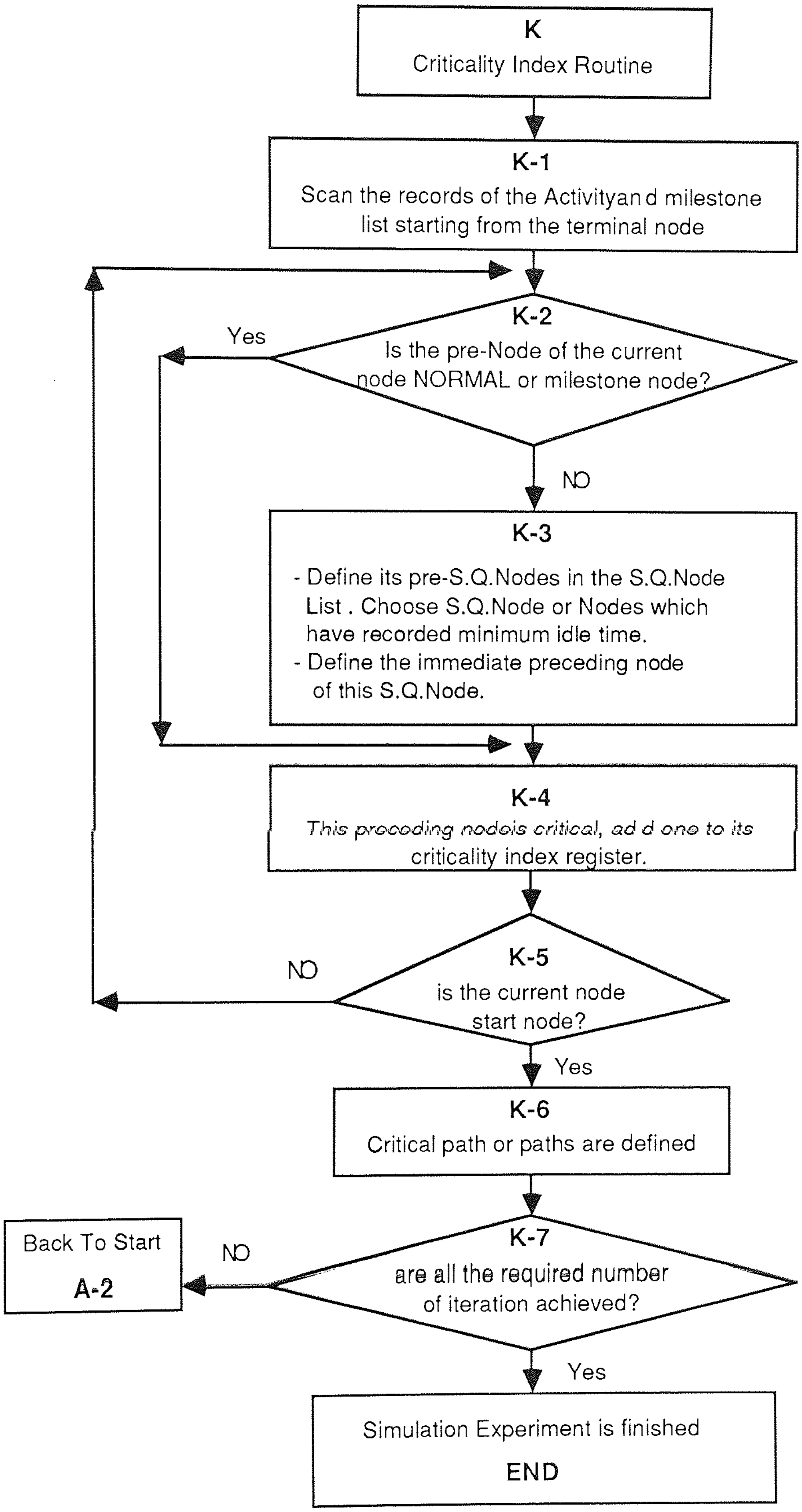


Figure (5-23)-Criticality Index Ro utine.

5.6. Balancing Resources :

The first simulation run may not satisfy the project targets or may result in non-zero idle time for some resources. In this case, the model has to be manipulated using the output of the simulation as a guide to obtain zero idle time schedule and satisfy the project targets. The process of manipulating the model is based on the idea that a minimum cost schedule can be obtained when the resource input and their idle time are kept to a minimum.

The author started developing a set of algorithms to computerize the manipulation process, but because the number of possibilities is large and the process needs to rely on a knowledge based system, this area is left for future research (chapter nine, para 2-b). A set of heuristic rules are developed to achieve the balancing of resources and satisfying the project targets. They can be considered as a base for computerization. They are :

1 - Rank the resources in the descending order of their idle time cost.

2- Study the record of each of these resources, define bottlenecks and the critical resources which have recorded zero idle time and interrupted the progress of the resources in question.

3 - Study the critical resources in the order of their effects, and consider the following options for each:

a-change the deployment points.

b-change the sequence of its activities.

4 - Consider the following courses of action for each of the idle resources:

a-change the deployment points.

b-change the sequence of its activities.

c-decrease its level at the bottleneck points, and increase the level at the points where there are critical activities, provided that the change will not result in a part of the resource staying idle.

5 - Consider increasing the level of the cheapest critical resource.

6 - Consider overtime for the cheapest critical resource.

7- Consider a planned break for the idle resources. In other words, plan a return visit to the site by those resources whose activities spread along different stages of the project (e.g. finishing trades in building project have 1st and 2nd fixing activities).

After manipulating the model, the simulation will be run again for the same number of iterations to allow comparison. The experienced planner or site manager can get the desired schedule within two attempts.

5.7. Summary Of The Procedures Of Using The Model :

1 - Prepare summary Project Breakdown Structure (PBS) chart.

2 - Define the method of working and the technology to be used.

3 - Prepare a summary plan (master plan) using C.P.M or Bar Chart.

4 - Produce an estimate for the time duration of each activity and the cost of resources.

5 - Produce a summary schedule showing the project targets at each stage, and work out a rough estimate for the required resources.

6 - Expand the (PBS) chart to the level of detail suitable for the construction phase.

7- Design a main network for each part of the project, then link these to obtain the main network for the project as a whole.

8 - Define the level of each type of resource and design a resource flow network for each.

9 - Prepare cost estimate for each type of resource and time estimates for each activity.

10 - Compile the utility data and the sequencing logic information in a list.

11 - Conduct the simulation experiment and analysis.

12- If the output schedule has zero idle time for all resources and meets the project target, then end.

13- Study the flow of each resource, define the bottlenecks and decide a course of actions.

14- Change the utility data of the nodes affected by the chosen actions.

15- Go to step 11 to repeat the process until satisfied.

The next chapter introduces the structure of the software, its analysis, and outputs. The case study in chapter seven demonstrates in detail how the model can be used and its capability.

Chapter Six

Software Structure, Its Input-Output And Analysis

6.1. Introduction :

The advances achieved in semiconducting and computer technology since the turn of this decade produced small, powerful, cheap and portable computers. The mass production of these machines makes it possible for almost everybody in any business to use computers for handling administrative works and the data generated throughout the business. Nowadays, microcomputers with very powerful capacity are available in the market with cost less than a small car. This means that any contractor can afford to buy the hardware necessary for site operations.

The major objective of the developed technique is to help site personnel to plan and control their work. This means that the software required should be written for microcomputer use to enable the site staff to use the technique and its analysis. This also means that the input procedure should be clear, user friendly and understandable for those people with no knowledge of programming. The output of the analysis should be in a format suitable for direct use by the site staff.

The software is written for an ACT-Apricot PC-XI microcomputer with the following capacity :

- 256 KB(kilobytes) expanded to 768 KB.
- 8087 mathcoprocessor to speed the mathematical calculations.
- 5 MB winchester disk storage.
- 315 KB floppy disk storage.

MS-DOS version 2.11 is used as an operating system, and Micro-Soft BASIC version 5.28 as a programming language to develop all the programs. The compiled version of the package is produced, after validating the structure and the input-output of all the programs, using Micro-Soft BASIC Compiler version 5.38.

The final version of the package reaches 387034 bytes in size in a compiled form.

6.2. The Development Process And Difficulties :

The purpose of this chapter is to introduce and describe the software and to provide some guide to the way in which it can be used. The chapter begins with assessment of the difficulties encountered during the work in developing the software and validating its structure.

It is understood that the only way of validating the structure and the output of any computer program is to run the computerized model by hand and compare the output of each stage with the output produced by the computer.

For analytical models based only on mathematics, the validating process is straightforward and relatively easy, but with simulation systems as is the case of the current model, this process needs team-work because of the sheer volume of input and output data and the complexity of the analysis.

A hypothetical project was designed for the purpose of developing the software and validating its internal logic and analysis. Its activities and their time durations cover all types of nodes and probability distributions of the model.

This hypothetical project is used in this chapter to introduce the input-output of the package and its capability.

The package consists of a flexible data base for storing the data required to represent the model and to run the simulation; a simulation routine; and a set of programs to produce reports on the simulation experiment and its analysis.

The format of the records for all types of node introduced in chapter five (see figures 5-1 to 5-12) is used for developing the necessary data files in the programs.

The structure of the package is divided into three separate modules : Input, simulation, and output modules. They comprise thirteen main programs to handle the input, the simulation process, and the output of the model. Another five programs are designed to control the access to the main programs and to regulate the transfer of data between them. This is achieved through eighteen main menus and several sub-menus within the software structure.

Each program of the input module creates a random access file to store part of the input data. It has several subroutines which provide a facility for adding, deleting, changing, sorting, and accessing any piece of information stored in the data file.
The structure of each data file is designed to match the form of records introduced in chapter five (see section 5.4).

The utility data of the hypothetical project are used to design and debug all the programs of the input module. The main difficulty here is not only to design a flexible data base which can be linked to other programs in the future, but also to provide error trap routines to prevent inputting the wrong data to the wrong file.

Many prompts are provided in all programs to draw the user's attention to the wrong input which provides the opportunity to correct any mistakes.

The second part of the package is the simulation module. It represents the core of the software. The speed of calculation and data processing is a crucial factor affecting the efficiency and usability of computer simulation. It would not be practical if each iteration of the simulated model takes too long a time to achieve.

For this reason extensive efforts have been made to design a simulation program which can achieve simulation with maximum speed. A special program is designed to create what are called working data files. This program checks all the data files created by the input module to make sure that all the data required for simulation are input to the system, otherwise the program instructs the user to go back to the input module to provide complete data for the system. If the data are complete, this program creates new data files which have the same utility data as the original data files, but their records are linked together according to the sequencing logic between the nodes of the main and resource flow networks.

With this method each record in each file is linked at the front and back ends to the appropriate records in the same file or another file according to the logic in the technique. This eliminates the need for searching the data files (which takes considerable time) throughout the simulation process.

The validating stage of this program took plenty of effort and a long time to achieve. At each point a printout of the content of all the records of eleven data files are produced and checked figure by figure to make sure that the program transfers and links the right information to the right records in the new data files. When any error is spotted in the program, the process is repeated again, and in many cases the structure of the original data files are changed in order to produce more efficient codes and gain more speed for the simulation process. Obviously, this results in the need for debugging the input module again and again. This validation process took many months to achieve.

The second major program of the simulation module contains the actual simulation routines and analysis. This program relied on the working data files created by the previous program for loading the required data and storing the result of the simulation process and analysis.

The main problem of validating the internal structure and the output of this program is the enormous volume of coded data which the program handles throughout each iteration.

In order to make sure that the program follows the algorithms of the model and produces correct results, an iteration of the hypothetical project network is performed on the computer. The values of all random numbers, and all lists of coded data used and produced by the program throughout this iteration are printed out. Then the network is simulated by hand using the same random numbers which are used in the computer run. By comparing the data generated at each stage in both hand simulation and computer run, errors in the structure and the output of the program are defined and corrected. One can imagine the difficulties of this process and the length of time required to achieve it. In correcting each error, the author had to work through more than 500 pages of tables full of figures and codes to make sure that the results obtained using the program match those produced by hand simulation.

The third part of the package is the report module. Validating this model was relatively easy, and less time consuming than the other two. Because it displays and prints out the results produced by the simulation module which is already debugged and validated.

The development of the package together with the daunting problems of these validation procedures consumed considerable time of this research.
The following sections introduce the hardware requirement to use the package , describe the structure and the input-output of each program in detail.

6.3. Hardware Requirements :

The aim of designing the package in the form of modules and separate programs is to minimize the need for keeping the whole package inside the RAM. Each part of each module can be loaded from the external storage separately and automatically by a set of main menus designed for this purpose.

The simulation routine is designed to rely on external storage for loading the necessary input data and for storing the output of the simulation. This puts no restriction on the size of the network the package can handle, because the network data are not stored in the RAM.

The minimum hardware requirements for using the package are:

- A microcomputer that can use any version of MS-DOS as an operating system.
- A minimum of 256 KB RAM to accommodate the operating system and the simulation routines.
- External storage with a minimum capacity of 600 KB, 400 KB to store the package and 200 KB for storing the input-output of a medium size network.
- A printer to produce hard copy of the output schedule and the analysis.

6.4. The Structure Of The Package :

A small program called " VC.EXE" is designed to display summary information on the structure and functions of the package. The user can start the package by typing "VC" which loads the "VC.EXE" program and displays the information that guides him through all parts of the package. The "CR" key loads the program called "MM.EXE" which displays the main menu of the package which is shown on table (6-1).

<u>VERT-CYCLONE main menu</u>

1- Input Module.

2- Simulation Module.

3- Report Module.

4- <u>Exit To The System.</u>

Table(6-1) - Main menu.

This menu gives the user the opportunity to access each part of the package and also to exit the package to the operating system.

The program "MM.EXE" channels on the request of the user. It loads one of the following programs:

- IM.EXE (to load the menu of the Input Module).
- SM.EXE (to load the menu of the Simulation Module).
- RM.EXE (to load the menu of the Report Module).

On exiting the package, "MM.EXE" program closes all the opened files and passes control to the operating system.

6.4.1. Input Module :

The input module consists of six separate programs designed to create data files for the project networks and the utility data. The structure of the data files mirrors the records of all the types of node introduced in chapter five (see figures 5-1 to 5-12).

This module allows the user to create the data base for the new project and to change the data of an on-going project or of the project under study.
Each of the programs has a large number of prompts to guide the user. There is also an extensive list of error messages. When option (1) is chosen in the main menu (see table 6-1), the program "MM.EXE" loads automatically from the external storage the program "IM.EXE" which displays the Input Module main menu which is shown on table (6-2).

The first six options of this menu are designed to create six different random access data files representing the structure of the project's main network and the flow networks for all the necessary resources.

Three types of resource are modelled in this data base: Labour, machinery, and equipment and tools (such as scaffolding, concrete slipform ...etc).

Input Module Menu

1-Summary Data On Project Network Specifications And Resource Flow Networks.

2-Detailed Data On The Activity And Milestone Nodes.

3-Detailed Data On The Space Queue And Function Nodes.

4- Detailed Data On The Labour Resource Network.

5- Detailed Data On The machinery Resource Network.

6- Detailed Data On The Equipment Resource Network.

7- Return To The Main Menu.

8- Exit To The System.

Table (6-2) - Input Module Menu.

6.4.1.1. Project Network Specification Data File :

The first option of the input module menu loads a program called "NET.EXE ". This program creates a data file containing general information on the project network and resources. This data file has one record only of 255 bytes, and has a six letter name with "DAT" as an extension.

The first three letters of the name of any data file in the package represent the project number (to distinguish between the data base of different projects). The second three letters are used to mark the type of the data file.

For example : P10SPC.DAT represents a data file containing the specification (SPC) of the network and the resources for the project number (10). DAT stands for data file.

The aim of creating this type of file is to control the structure and the number of records of other detailed data files of the same project.

The program "NET.EXE", at the start, displays a menu which allows the user to create a data file for a new project, to change the content of the same type of file of the project under study or under control, and to list the content of the file to check if any part of it is in need of change. The structure of this menu is shown on table (6-2-1). All input module programs have the facility to produce hard copy of the content of the data file they create. This gives the user the opportunity to check his input. Also, several error trap routines are built into the structure of each program which warn the user of any illogical input, and give him the chance to check the input and correct it if necessary.

Project Network Specification Input Menu

1- Create A Data File For A New Project.

2- Change A network Specification Of An Old Project.

3- List A Network Specification.

4- Return To Input Module Menu.

Table (6-2-1) - Project Network Specification Input Menu.

A print-out of the content of the SPC.DAT file of the hypothetical project is shown on figure (6-1).

The main network of this project has 24 activity and milestone nodes, 29 Space Queue and Function nodes, 8 labour resource categories, and 2 machinery resource categories. The flow network of each resource category has a different number of Resource Queue nodes.

6.4.1.2. Activity And Milestone Nodes Data File :

The second program of the input module which is loaded by the second option on the menu (table 6-2) is called "IA.EXE". This program creates a random access file for storing data on the network activities and milestones. The data for each node are stored in one record of 255 bytes. The file created by the program is stored under the name AND.DAT. Figure (6-2) shows a sample of the content of this type of file.

In this figure the data of each node includes: the technological logic controlling its position in the main network; the resource dependencies (i.e. preceding and succeeding Resource Queue nodes); the time duration (type and values), and the fixed and variable costs.

The program "IA.EXE" has a main menu shown on table (6-2-2-a), and a secondary menu shown on table (6-2-2-b). This is to facilitate the process of creating a detailed data file on the activity and milestone nodes of a new project, deleting or, adding new nodes to an old project network, and changing the utility data of some nodes of an old project network.

Main Network Data Input(main menu)

1- Create A Data File For The Network Of A New Project.

2- Change The Network Of An Old Project.

3- Return To The Input Module Menu.

Table (6-2-2-a)

PROJECT NETWORK GENERAL INFORMATION.
****

PROJECT DESCRIPTION :

SCHOOL BUILDING

NETWORK SPECIFICATION.
****

1-NO OF ACTIVITY AND DECISION NODES (MAX 9999): 24
2-NO OF SPACE Q-NODES AND FUNCTION-NODES(MAX 9999) : 29

GENERAL INF ON THE RESOURCES INVOLVED.
****

A-LABOUR RESOURCE.

-NO OF LABOUR RESOURCE CATEGORIES INVOLVED (MAX 50): 8

1 -NO OF Q-NODES(MAX 99) OF LABOUR CATEGORY NO : 1 IS : 2
2 -NO OF Q-NODES(MAX 99) OF LABOUR CATEGORY NO : 2 IS : 2
3 -NO OF Q-NODES(MAX 99) OF LABOUR CATEGORY NO : 3 IS : 3
4 -NO OF Q-NODES(MAX 99) OF LABOUR CATEGORY NO : 4 IS : 3
5 -NO OF Q-NODES(MAX 99) OF LABOUR CATEGORY NO : 5 IS : 3
6 -NO OF Q-NODES(MAX 99) OF LABOUR CATEGORY NO : 6 IS : 2
7 -NO OF Q-NODES(MAX 99) OF LABOUR CATEGORY NO : 7 IS : 2
8 -NO OF Q-NODES(MAX 99) OF LABOUR CATEGORY NO : 8 IS : 2

B-MACHINARY RESOURCE.

-NO OF MACHINARY RESOURCE CATEGORIES INVOLVED (MAX 20): 2

1 -NO OF Q-NODES(MAX 99) OF MACHINARY CATEGORY NO : 1 IS : 2
2 -NO OF Q-NODES(MAX 99) OF MACHINARY CATEGORY NO : 2 IS : 4

C-EQUIPMENT RESOURCE.

-NO OF EQUIPMENT RESOURCE CATEGORIES INVOLVED (MAX 20): 0

Figure (6-1)- The Content Of Project Network Specification Data File.

DETAIL DATA OF THE MAIN NETWORK

****

1 NODE'S LABEL : d- 5
NODE'S TYPE : 28
NODE'S DES : START

NO.OF.SUCC-NODES: 3

NO	LABEL
1	s- 15
2	s- 20
3	f- 10

NO.OF.SUCC-R-Q-NODES: 1

LABEL	NO.UNIT
m 1 - 1	1

STARTING TIME= 10 INITIAL COST= 1000

2 NODE'S LABEL : a- 25
NODE'S TYPE : 10
NODE'S DES : EXCAV-I

NO	NO.OF.PRE NODES: 1 LABEL	NO.OF.SUCC NODES: 1 LABEL	NO.OF.PRE R-Q-NODES: 1 LABEL	NO.UNI	NO.OF.SUCC R-Q-NODES: 2 LABEL	NO.UNI
1	s- 15	s- 35	m 1 - 1	1	m 1 - 1	1
2					l 1 - 1	2

ESTIMATED TIME DURATION :

TYPE	MIN	MAX	MEAN	S.D
NORMAL	6	4.5	7.5	.5

FIXED COST= 1000 VARIABLE COST/TIME UNIT= 500

3 NODE'S LABEL : a- 30
NODE'S TYPE : 10
NODE'S DES : EXCAV-II

NO	NO.OF.PRE NODES: 1 LABEL	NO.OF.SUCC NODES: 1 LABEL	NO.OF.PRE R-Q-NODES: 1 LABEL	NO.UNI	NO.OF.SUCC R-Q-NODES: 1 LABEL	NO.UNI
1	s- 20	s- 40	m 1 - 1	1	m 1 - 1	1

ESTIMATED TIME DURATION :

TYPE	MIN	MAX	MEAN	S.D
NORMAL	5	4.25	5.75	.25

FIXED COST= 700 VARIABLE COST/TIME UNIT= 500

Figure (6-2)- Activity And Milestone Nodes Data File.

```
 8  NODE'S LABEL : a- 75
    NODE'S TYPE  :  11
    NODE'S DES   : CURING-I
    ----------------------------------
         NO.OF.PRE-N: 1     NO.OF.SUCC-N: 1       NO.OF.SUCC-RN: 0
         --------------     --------------        ----------------
 NO            LABEL              LABEL           LABEL    NO.UNIT
 ----          -----              -----           -----    -------
  1            a- 65              s- 85
ESTIMATED TIME DURATION :
---------------------------
  TYPE         DURATION
 --------      --------
CONSTANT          7
--------------------------------------------------------------------

10 NODE'S LABEL : d- 95
   NODE'S TYPE  :  18
   NODE'S DES   : FRAMWORK IS FINISHED
   ----------------------------------
        NO.OF.PRE-N: 2     NO.OF.SUCC-N: 2       NO.OF.SUCC-RN: 1
        --------------     --------------        ----------------
NO            LABEL              LABEL           LABEL    NO.UNIT
----          -----              -----           -----    -------
 1            s- 85              f- 100          1 2 - 1     1
 2            s- 90              s- 105

TIME CONSTRAINT=  48                      COST CONSTRAINT=  33600
---------------------------------------------------------------------------

11 NODE'S LABEL : a- 110
   NODE'S TYPE  :  10
   NODE'S DES   : B.WORK
   ----------------------------------
     NO.OF.PRE      NO.OF.SUCC          NO.OF.PRE            NO.OF.SUCC
     NODES: 1       NODES: 3            R-Q-NODES: 1         R-Q-NODES: 4
    ----------     -----------         -------------        -------------
NO  LABEL          LABEL               LABEL   NO.UNI       LABEL   NO.UNI
--- -----          -----               -----   ------       -----   ------
1   s- 105         s- 115              1 2 - 1    1         1 2 - 2    1
2                  s- 120                                   1 3 - 1    1
3                  s- 125                                   1 4 - 1    1
4                                                           1 5 - 1    1
ESTIMATED TIME DURATION :
---------------------------
  TYPE          MIN          MAX
 --------     -------      -------
UNIFORM         6            8

FIXED COST=  2000                        VARIABLE COST/TIME UNIT=  400
---------------------------------------------------------------------------

 24 NODE'S LABEL : d- 265
    NODE'S TYPE  :  27
    NODE'S DES   : END
    ----------------------------------

NO.OF.PRE-NODES=  3
--------------------
     NO          LABEL
    ----        -------
     1           s- 260
     2           f- 10
     3           f- 100

TIME CONSTRAINT=  93                      COST CONSTRAINT=  80000
--------------------------------------------------------------------
```

Figure (6-2)- Continued.

Main Network Data Input(secondary menu)

1- Change The Data Of The Network.

2- Add Or Delete Nodes Within The Network.

3- List The Contents Of The ADN.DAT File.

4- Print The Content Of The ADN.DAT File.

5- Return To The Previous Menu.

Table (6-2-2-b)

The secondary menu is loaded by the second option of the main menu.

The program sorts the records of the ADN.DAT file in the ascending order of the node's number in the main network. It also contains a search routine, by which the record of any represented node can be accessed and displayed on the screen. All the programs of the input and report modules have the facility of sorting and searching the data file.

6.4.1.3. Space Queue And Function Nodes Data File :

The third program of the input module is called "SI.EXE". This program creates a random access file called SQN.DAT, with a record size of 100 bytes. This file stores detailed data on the Space Queue and Function nodes in the main network. Figure (6-3) shows a sample of the content of this file.

In this figure, the node number 10 represents a BETWEEN node which models the overhead cost. Nodes 15, 20, and 260 are Space Queue nodes which represent the idle state of work locations. Node number 100 represents the ACCUMULATOR node which accumulates the cost along the network. Like "IA.EXE", "SI.EXE" has two menus, a main menu shown on table (6-2-3-a), and a secondary menu shown on table (6-2-3-b).

```
COPY OF THE CONTENT OF SQN.DAT FILE.
THIS FILE HAS:  29   SQNODES.
************************************

1  NODE'S NUMBER=  10
   NODE'S  TYPE =  1
   NODE'S DESCRITION: OVERHEAD-COST
   ----------------------------------------
   PRE-NODE'S NUMBER OR NO OF NODES PRE-ACC NODE=  5
   SUCC-NODE'S NUMBER:  265
   COST/TIME UNIT=  100
   ----------------------------------------------------

2  NODE'S NUMBER=  15
   NODE'S  TYPE =  3
   NODE'S DESCRITION: READY TO EXCAV-I
   ----------------------------------------
   PRE-NODE'S NUMBER OR NO OF NODES PRE-ACC NODE=  5
   SUCC-NODE'S NUMBER:  25
   ----------------------------------------------------

3  NODE'S NUMBER=  20
   NODE'S  TYPE =  4
   NODE'S DESCRITION: READY TO EXCAV-II
   ----------------------------------------
   PRE-NODE'S NUMBER OR NO OF NODES PRE-ACC NODE=  5
   SUCC-NODE'S NUMBER:  30
   ----------------------------------------------------

10 NODE'S NUMBER=  100
   NODE'S  TYPE =  2
   NODE'S DESCRITION: ACC-COST
   ----------------------------------------
   PRE-NODE'S NUMBER OR NO OF NODES PRE-ACC NODE=  2
   SUCC-NODE'S NUMBER:  265
   ----------------------------------------------------

29 NODE'S NUMBER=  260
   NODE'S  TYPE =  4
   NODE'S DESCRITION: PAINTING FINISHED
   ----------------------------------------
   PRE-NODE'S NUMBER OR NO OF NODES PRE-ACC NODE=  255
   SUCC-NODE'S NUMBER:  265
   ----------------------------------------------------
```

Figure (6-3)- Space Queue And Function Nodes Data File.

Space Queue And Function Nodes Data Input(main menu)

1-Create S.Q.Nodes And Function Nodes Data File For A New Project.

2-Change, List, Produce Hard Copy Of The Content Of SQN.DAT File Of An Old Project.

3-Return To Input Module Menu.

Table (6-2-3-a)

Changing Data Of S.Q.Nodes Data File Menu

1-Change The Data Of S.Q. And Function Nodes.

2-Add New S.Q. And Function Nodes To The File.

3-List The Content Of The SQN.DAT File.

4-Produce Hard Copy Of The Content Of The SQN.DAT File.

5-Return To The Previous Menu.

Table (6-2-3-b)

6.4.1.4. Resource Data Files :

The other three programs of the input module are designed to create data files for each type of resource (labour, machinery, and equipment and tools).
The structure of these programs is the same. They are called "LI.EXE" (for labour resource), "MI.EXE" (for machinery resource), and "EI.EXE" (for equipment and tool resource).

Each program creates a random access file with a record size of 100 bytes. These files are: LQN.DAT, MQN.DAT, and EQN.DAT. A number of records equal to the number of resource categories are allocated at the beginning of the file to store data on each resource category.

These data include : the number of Resource Queue nodes in the flow network of this resource category this record represents, a description of the resource category,

```
A COPY OF THE CONTENT OF LQNODES DATA FILE.
*********************************************

DATA OF LABOUR RESOURCE CATEGORY NO= 1
****************************************

THE NUMBER OF RQNODES      = 2
LABOUR CATEGORY DES        :FORMWORK CREW
UNIT RATE/TIME UNIT        = 700
---------------------------------

1  NODE'S NUMBER= 1
   NODE'S TYPE  = 8
   -----------------
   PRE-NODE'S NUMBER= 25
   PRE-NODE'S TYPE  = 10
   --------------------
   NO.OF.SUCC-NODES= 3
     NO      SUCC-NODE NO     SUCC-NODE TYPE
    ----     ------------     --------------
     1            45                10
     2            50                10
     3            2                 9
   ---------------------------------------

2  NODE'S NUMBER= 2
   NODE'S TYPE  = 9
   -----------------
   PRE-NODE'S NUMBER= 1
   PRE-NODE'S TYPE  = 8
   NO.OF.UNITS      = 2
   ---------------------------------------

DATA OF LABOUR RESOURCE CATEGORY NO= 2
****************************************

THE NUMBER OF RQNODES      = 2
LABOUR CATEGORY DES        :B.WORK CREW
UNIT RATE/TIME UNIT        = 400
---------------------------------

1  NODE'S NUMBER= 1
   NODE'S TYPE  = 7
   -----------------
   PRE-NODE'S NUMBER= 95
   PRE-NODE'S TYPE  = 18
   SUCC-NODE'S NUMBER= 110
   SUCC-NODE'S TYPE  = 10
   ---------------------------------------

2  NODE'S NUMBER= 2
   NODE'S TYPE  = 9
   -----------------
   PRE-NODE'S NUMBER= 110
   PRE-NODE'S TYPE  = 10
   NO.OF.UNITS      = 1
   ---------------------------------------
```

Figure (6-4) A Sample Of The Content Of LQN.DAT File.

and the cost of the resource unit/time unit. The rest of the records are allocated for storing data on the Resource Queue nodes of each resource category.

A sample of the content of LQN.DAT file is shown on figure (6-4).

Each of the resource data programs (LI.EXE, MI.EXE, and EI.EXE) has a main menu shown on table (6-2-4-a) and a secondary menu shown on table (6-2-4-b). The program sorts the records of this data file in the ascending order of the resource category and the Queue node's numbers of its flow network.

Labour Resource Queue Nodes Data Input(main menu)

1-Create L.R.Q.Nodes Data File For The New Project.

2-Change, List And Produce Hard Copy Of The Content Of L.R.Q.Nodes Data File.

3-Return To The Input Module Menu.

Table (6-2-4-a)

Labour R.Q.Nodes Data Input(secondary menu)

1-Change The Data Of The L.R.Q.Nodes.

2-Cancel Some L.R.Q.Nodes.

3- Add New Resource Queue Nodes To LQN.DAT File.

4-List Part Or The Whole Content Of LQN.DAT File.

5-Produce Hard Copy Of The Content Of LQN.DAT File.

6-Return To The Previous Menu.

Table (6-2-4-b)

6.4.2. Simulation Module :

As mentioned earlier, the simulation module has two large programs. The first program is called "S1.EXE", it is designed to create working data files for the simulation process. During the simulation, each record of each of the data files created by the input module has to be accessed to retrieve the necessary data on the sequencing logic, time, and cost.

This requires a continual search of all the random access files which is time expensive, increasing the calculation time of the network and reducing the efficiency of the simulation program. The "S1.EXE" has the following functions :

-To scan the SPC.DAT file to ensure that the detailed data files (ADN.DAT, SQN.DAT, RQN.DAT files) are created and have the necessary data for the simulation process.

-To create new data files which have the same data as the original data files, but in a coded form and their records are linked together forward and backward according to the sequencing logic stated in all the networks. These working files are : AND.SIM, SQN.SIM. and RQN.SIM files.

The second program is called "S2.EXE". It conducts the simulation process and analyses its output. The structure of this program is based on the same simulation algorithms which are introduced in chapter five. A large number of subroutines were designed to handle all types of logic and control the flow of the simulation process.

Throughout the simulation, the program accesses all the working files to load the necessary input data in the memory and store the output data in the relevant file. Also, the program creates a random access file called TER.SIM to sore the completion time, the net cost, the idle time cost of all resources, and the total cost of the project at each iteration. At the end of the simulation this file and part of the structure of the other working files will have statistics on the time and cost of each activity, each stage and the project as a whole.

The program has a set of statistical analysis routines which access these files to conduct statistical analysis on the simulation outputs and store the results in a special section of the structure of the working files and TER.SIM file.

The simulation module is loaded by the second option of the main menu (table 6-1). The program "MM.EXE" loads the simulation module menu program "SM.EXE". This program displays the simulation menu of which is shown on table (6-3).

Simulation Module Menu

1-Create Working Files.

2-Run Simulation And Statistical Analysis.

3-Return To The Main Menu.

4-Exit To The System.

Table (6-3)

The first option of this menu loads the program "S1.EXE" which creates the working files. The "S1.EXE" program has a menu as well to allow the user access to the input module menu in case the necessary data files are not complete.
The structure of its menu is shown on table (6-3-1).

Working Files Menu

1-Create Working Files For The Simulation Process.

2-Exit To The Input Module Menu.

3-Return To The Simulation Module Menu.

Table (6-3-1)

The second option in table (6-3) loads the simulation program "S2.EXE". This program checks whether all the necessary working data files are created. If not, the program prompts the user to go back to the simulation module menu and then to the input module menu to create what is necessary. The menu provided in this program is shown on table (6-3-2).

Network Simulation Experiment Menu

1-Run Simulation And Statistical Analysis.

2-Return To The Simulation Module Menu.

Table (6-3-2)

The number of iterations is input by the user, and the program displays on the screen an estimate of the time duration of each iteration and for the simulation experiment as a whole.

6.4.3. Report Module :

The function of this module is to produce a report on the output of the simulation on the main network and resources. It consists of five programs : one for reporting on the activity and milestone nodes, the second to report on Space Queue and Function nodes, and the other three, report on each type of resource (labour, machinery, and equipment and tools). The third option of table (6-1) loads a program called "RM.EXE" which displays the menu of the report module. Table (6-4) shows the structure of this menu.

Report Module Menu

1-Activities And Milestones Report.

2-Space Queue And Function Nodes Report.

3-Labour Resource Report.

4-machinery Resource Report.

5-Equipment And Tool Resource Report.

6-Return To The Main Menu.

7-Exit To The System.

Table (6-4)

6.4.3.1. Activities And Milestones Report :

The first option of this module loads the program called "All.EXE" which produces summary and detailed reports on the main network. It displays the following menu (table 6-4-1).

Activity And Milestone Report Menu

1-Summary Report.

2-Detailed Report.

3-Return To The Report Module Menu.

Table (6-4-1)

"All.EXE" has summary report menu shown on table (6-4-1-a).

Summary Report Menu

1-Display A Summary Report On Milestone And Terminal Nodes.

2-Produce A Hard Copy Of The Summary Report On Milestone And Terminal Nodes.

3-Display A list Of Milestone And Activity Nodes In The Descending Order Of Their Criticality Index.

4-Produce A Hard Copy Of A List Of Milestone And Activity Nodes In The Descending Order Of Their Criticality Index.

5-Return To The Previous Menu.

Table (6-4-1-a)

Figures (6-5) and (6-6) show a summary report on milestone and terminal nodes.

The aim of this report is to show if the project targets can be achieved or not. It serves the purpose of the top level of management and links the detailed plan with the summary or master plan.

MILESTONES & TERMINAL NODE REPORT.
****

```
NODE'S NUMBER= 5              NODE'S TYPE= 28           C-INDEX= 1
STARTING TIME= 10             INITIAL COST= 1000
                    ------------------------------

NODE'S NUMBER= 95             NODE'S TYPE= 18           C-INDEX= 1
TIME CONSTRAINT= 48           PROB.OF.ACHIEVING IT= 1
COST CONSTRAINT= 33600        PROB.OF.ACHIEVING IT= 1
                    ------------------------------

NODE'S NUMBER= 160            NODE'S TYPE= 12           C-INDEX= 1
                    ------------------------------

NODE'S NUMBER= 195            NODE'S TYPE= 12           C-INDEX= 1
                    ------------------------------

NODE'S NUMBER= 245            NODE'S TYPE= 12           C-INDEX= 1
                    ------------------------------
```

Figure (6-5)- Summary Report On Milestones And Terminal nodes.

On figure (6-5), the node 5 is a starting node. The starting time 10 which means that the project starts at day number 10, with an initial cost of £1000. Its criticality index is equal to unity or %100.

The milestone node 95 has to be realized on day 48 or before with cost equals to £33600 or less. The probability of achieving these time and cost targets are 1, 1 or %100,%100 respectively. Its criticality index is unity which means that it is critical on each iteration.

The program "AII.EXE" accesses the TER.SIM file to retrieve the necessary data to draw the probability and the cumulative distributions for each parameter of the terminal node. Figures (6-6-a) to (6-6-h) show these distributions. Also the following information is displayed under each of them:

-The type of the terminal node (TERMINAL-1,2,3) (the type is given a code in the program).

-The number of iterations achieved.

-The time or cost constraint (where applicable).

-The probability of achieving the time target (TCI-Index), the probability of achieving the cost target through the net cost (CCI-Index), and the probability of achieving the cost target through the total cost (CCVI-Index).

-Minimum, maximum, mean, and standard deviation values of the distribution.

-Coefficient of variation (C.O.V) which is the ratio of the standard deviation to the mean.

The aim of producing this parameter is to compare the distribution of time with different cost distributions.

-Mode value and its probability of occurrence. This is to give the user an idea of the most likely value of the parameter in question and its weight.

-The Pearsonian skew value which is the difference between the mean and the mode value.

```
                    HARD COPY OF TERM NODE'S PARA DIST.
                    ***********************************


      0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
   MIN-I----I----I----I----I----I----I----I----I----I----I----I
 72.11-I*.................................................0.020
 72.66-I..................................................0.000
 73.20-I***............................................... 0.070
 73.74-I****.............................................. 0.100
 74.29-I********..........................................0.160
 74.83-I************...................................... 0.240
 75.37-I********..........................................0.160
 75.92-I*****............................................. 0.110
 76.46-I***...............................................0.070
 77.01-I*.................................................0.030
 77.55-I*.................................................0.020
 78.09-I..................................................0.010
 78.64-I..................................................0.010
   MAX-I----I----I----I----I----I----I----I----I----I----I----I
   TN-TYPE   = 27             MIN   =  72.11      MODE VALUE=  74.83
   NO.OF.OBS= 100             MAX   =  78.64      MODE PROB =   0.240
   TIME-CONS= 93              MEAN  =  74.96      PEAR SKEW =   0.13
   TCI-INDEX=1.000            S.D   =   1.183     PEAR-COFF =   0.113
                              C.O.V=    0.016

                        (a)-PDF OF COPMLETION TIME.
                        ---------------------------


      0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
   MIN-I----I----I----I----I----I----I----I----I----I----I----I
                                                          0.000
 71.84-I..................................................0.020
 72.38-I*.................................................0.020
 72.93-I*................................................. 0.090
 73.47-I****.............................................. 0.190
 74.01-I*********......................................... 0.350
 74.56-I*****************.................................0.590
 75.10-I*****************************..................... 0.750
 75.65-I*************************************.............0.860
 76.19-I*******************************************....... 0.930
 76.73-I**********************************************....0.960
 77.28-I************************************************..0.980
 77.82-I*************************************************. 0.990
 78.36-I*************************************************.1.000
 78.91-I**************************************************
   MAX-I----I----I----I----I----I----I----I----I----I----I----I
   TN-TYPE   = 27             MIN   =  72.11      MODE VALUE=  74.83
   NO.OF.OBS= 100             MAX   =  78.64      MODE PROB =   0.240
   TIME-CONS= 93              MEAN  =  74.96      PEAR SKEW =   0.13
   TCI-INDEX=1.000            S.D   =   1.183     PEAR-COFF =   0.113
                              C.O.V=    0.016

                        (b)-CDF OF COMPLETION TIME.
                        ---------------------------
```

Figure (6-6)- Time And Cost Distributions Of The Terminal Node.

```
       0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
    MIN-I----I----I----I----I----I----I----I----I----I----I----I----I
85105.16-I*.................................................0.020
85526.67-I..................................................0.010
85948.17-I**................................................0.050
86369.69-I******............................................0.130
86791.19-I*****.............................................0.110
87212.70-I*******...........................................0.150
87634.20-I********..........................................0.160
88055.72-I*********.........................................0.190
88477.22-I**................................................0.050
88898.73-I**................................................0.040
89320.23-I*.................................................0.040
89741.75-I**................................................0.040
90163.26-I..................................................0.010
    MAX-I----I----I----I----I----I----I----I----I----I----I----I----I
    TN-TYPE   = 27          MIN  =   85105.16       MODE VALUE=   88055.72
    NO.OF.OBS= 100          MAX  =   90163.26       MODE PROB =      0.190
    COST-CONS= 80000        MEAN =   87510.27       PEAR SKEW =     545.45
    CCI-INDEX=0.000         S.D  =    1020.243      PEAR-COFF =      0.535
                            C.O.V=       0.012

                            (c)-PDF OF NET COST.
                            --------------------
```

```
       0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
    MIN-I----I----I----I----I----I----I----I----I----I----I----I----I
84894.41-I..................................................0.000
85315.91-I*.................................................0.020
85737.42-I*.................................................0.030
86158.93-I****..............................................0.080
86580.44-I**********........................................0.210
87001.95-I****************..................................0.320
87423.45-I***********************...........................0.470
87844.96-I*******************************...................0.630
88266.47-I*****************************************.........0.820
88687.98-I*******************************************.......0.870
89109.48-I*********************************************.....0.910
89530.99-I***********************************************...0.950
89952.50-I*************************************************.0.990
90374.02-I**************************************************1.000
    MAX-I----I----I----I----I----I----I----I----I----I----I----I----I
    TN-TYPE   = 27          MIN  =   85105.16       MODE VALUE=   88055.72
    NO.OF.OBS= 100          MAX  =   90163.26       MODE PROB =      0.190
    COST-CONS= 80000        MEAN =   87510.27       PEAR SKEW =     545.45
    CCI-INDEX=0.000         S.D  =    1020.243      PEAR-COFF =      0.535
                            C.O.V=       0.012

                            (d)-CDF OF NET COST.
                            --------------------
```

Figure (6-6)- Continued.

```
           0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
       MIN-I----I----I----I----I----I----I----I----I----I----I----I----I
 11287.88-I*...........................................................0.020
 11563.55-I*...........................................................0.030
 11839.23-I**..........................................................0.040
 12114.91-I***.........................................................0.060
 12390.59-I****........................................................0.100
 12666.27-I******......................................................0.120
 12941.95-I****........................................................0.100
 13217.63-I*****.......................................................0.120
 13493.31-I********....................................................0.160
 13768.99-I*****.......................................................0.110
 14044.67-I****........................................................0.100
 14320.35-I*...........................................................0.020
 14596.03-I............................................................0.020
       MAX-I----I----I----I----I----I----I----I----I----I----I----I----I
       TN-TYPE   = 27          MIN   =   11287.88       MODE VALUE=   13493.31
       NO.OF.OBS= 100          MAX   =   14596.03       MODE PROB =      0.160
                               MEAN  =   13070.45       PEAR SKEW =     422.86
                               S.D   =    756.307       PEAR-COFF =      0.559
                               C.O.V=       0.058
```

(e)-PDF OF COST OF IDLE TIME OF RESOURCES.

```
           0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
       MIN-I----I----I----I----I----I----I----I----I----I----I----I----I
 11150.04-I............................................................0.000
 11425.71-I*...........................................................0.020
 11701.39-I**..........................................................0.050
 11977.07-I****........................................................0.090
 12252.75-I*******.....................................................0.150
 12528.43-I************................................................0.250
 12804.11-I******************..........................................0.370
 13079.79-I***********************.....................................0.470
 13355.47-I*****************************...............................0.590
 13631.15-I*************************************.......................0.750
 13906.83-I*******************************************.................0.860
 14182.51-I************************************************............0.960
 14458.19-I*************************************************...........0.980
 14733.87-I**************************************************..........1.000
       MAX-I----I----I----I----I----I----I----I----I----I----I----I----I
       TN-TYPE   = 27          MIN   =   11287.88       MODE VALUE=   13493.31
       NO.OF.OBS= 100          MAX   =.  14596.03       MODE PROB =      0.160
                               MEAN  =   13070.45       PEAR SKEW =     422.86
                               S.D   =    756.307       PEAR-COFF =      0.559
                               C.O.V=       0.058
```

(f)-CDF OF COST OF IDLE TIME OF RESOURCES.

Figure (6-6)- Continued.

```
            0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
        MIN-I----I----I----I----I----I----I----I----I----I----I----I----I
  98484.33-I.................................................. 0.010
  98913.35-I***...............................................0.060
  99342.37-I****..............................................0.080
  99771.38-I********..........................................0.170
 100200.40-I********..........................................0.160
 100629.41-I*******...........................................0.140
 101058.43-I********.......................................... 0.170
 101487.45-I***...............................................0.060
 101916.46-I***...............................................0.070
 102345.48-I*.................................................0.030
 102774.49-I..................................................0.010
 103203.51-I*................................................ 0.030
 103632.55-I..................................................0.010
        MAX-I----I----I----I----I----I----I----I----I----I----I----I----I
        TN-TYPE   = 27          MIN   =    98484.33     MODE VALUE=  101058.43
        NO.OF.OBS= 100          MAX   =   103632.56     MODE PROB =      0.170
        COST-CONS= 80000        MEAN  =   100580.70     PEAR SKEW =     477.73
        CCI-INDEX=0.000         S.D   =     1049.678    PEAR-COFF =      0.455
                                C.O.V=         0.010
```

(g)-PDF OF TOTAL COST.

```
            0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
        MIN-I----I----I----I----I----I----I----I----I----I----I----I----I
  98269.82-I..................................................0.000
  98698.84-I.................................................. 0.010
  99127.86-I***............................................... 0.070
  99556.88-I*******........................................... 0.150
  99985.89-I****************..................................0.320
 100414.91-I************************..........................0.480
 100843.92-I*******************************...................0.620
 101272.94-I***************************************.......... 0.790
 101701.95-I******************************************....... 0.850
 102130.97-I**********************************************....0.920
 102559.98-I***********************************************.. 0.950
 102989.00-I************************************************..0.960
 103418.02-I*************************************************. 0.990
 103847.07-I**************************************************1.000
        MAX-I----I----I----I----I----I----I----I----I----I----I----I----I
        TN-TYPE   = 27          MIN   =    98484.33     MODE VALUE=  101058.43
        NO.OF.OBS= 100          MAX   =   103632.56     MODE PROB =      0.170
        COST-CONS= 80000        MEAN  =   100580.70     PEAR SKEW =     477.73
        CCVI-INDEX=0.000        S.D   =     1049.678    PEAR-COFF =      0.455
                                C.O.V=         0.010
```

(h)-CDF OF TOTAL COST.

Figure (6-6)- Continued.

This gives an idea on the extent of the skewness of the distribution.

-The Pearsonian coefficient which is the ratio of the Pearsonian skew to the standard deviation.

A distribution can be considered markedly skewed if its absolute value of the Pearsonian coefficient is more than one.

Producing a cumulative distribution of each parameter is very useful as it gives the user the opportunity to define the probability of achieving any value of the parameter. For example : on figure (6-6-b), the project can be finished within 77 days or less with a probability of %93.

The second part of the summary report (table 6-4-1-a) is a list of the project activities and milestones in the descending order of their criticality index. Figure (6-7) displays this type of list.

This list shows the importance of each node in the main network in deciding the completion time. It is a useful report for management at head office and on site as it focuses attention on the most troublesome areas of the project.

The second option of the menu in table (6-4-1) is to produce a detailed report. This option has a separate menu shown on table (6-4-1-b).

Detailed Report Menu

1-Display Activity And Milestone Nodes Detailed Report.

2-Produce A Hard Copy Of A Detailed Report On The Activity And Milestone Nodes.

3-Return To The Previous Menu.

Table (6-4-1-b)

A LIST OF ADNODES IN THE DESCENDING ORDER OF CI.
****

SEQ	NODE'S NUMBER	NODE'S TYPE	C-INDEX
1	5	28	1
2	110	10	1
3	160	12	1
4	95	18	1
5	255	10	1
6	195	12	1
7	245	12	1
8	130	10	1
9	265	27	1
10	50	10	.99
11	70	10	.99
12	180	10	.99
13	80	11	.99
14	30	10	.99
15	225	10	.54
16	220	10	.25
17	215	10	.21
18	45	10	.01
19	25	10	.01
20	175	10	.01
21	75	11	.01
22	65	10	.01
23	135	10	0
24	140	10	0

Figure (6-7)- Activity And Milestone Nodes List In The Descending Order Of Their Criticality Index.

A COPY OF ADNODES DETAILED REPORT.
****

THE MAIN NETWORK HAS: 24 NODES.

NODE'S LABEL:d- 5 NODE'S TYPE: 28 C-INDEX= 1
NODE'S DESCRIPTION:START

NO	NO.OF.SUCC-N: 3 LABEL	NO.OF.SUCC-RN: 1 LABEL	NO.UNI
1	s- 15	m 1 - 1	1
2	s- 20		
3	f- 10		

STARTING TIME= 10 INITIAL COST= 1000
****

NODE'S LABEL:a- 25 NODE'S TYPE: 10 C-INDEX= .01
NODE'S DESCRIPTION:EXCAV-I

NO	NO.OF.PRE-N: 1 LABEL	NO.OF.SUCC-N: 1 LABEL	NO.OF.PRE-RN: 1 LABEL	NO.UNI	NO.OF.SUCC-RN: 2 LABEL	NO.UNI
1	s- 15	s- 35	m 1 - 1	1	m 1 - 1	1
2					l 1 - 1	2

FIXED COST= 1000 VARIABLE COST= 500

	TYPE	MIN	MAX	M-MEAN	S.D
STARTING TIME:	-	10.00	10.00	10.00	0.000
ESTIMATED DUR:	NORMAL	4.5	7.5	6	.5

****

NODE'S LABEL:a- 30 NODE'S TYPE: 10 C-INDEX= .99
NODE'S DESCRIPTION:EXCAV-II

NO	NO.OF.PRE-N: 1 LABEL	NO.OF.SUCC-N: 1 LABEL	NO.OF.PRE-RN: 1 LABEL	NO.UNI	NO.OF.SUCC-RN: 1 LABEL	NO.UNI
1	s- 20	s- 40	m 1 - 1	1	m 1 - 1	1

FIXED COST= 700 VARIABLE COST= 500

	TYPE	MIN	MAX	M-MEAN	S.D
STARTING TIME:	-	14.84	17.15	15.97	0.517
ESTIMATED DUR:	NORMAL	4.25	5.75	5	.25

****

Figure (6-8)- Activity And Milestone Nodes Schedule (detailed report).

```
NODE'S LABEL:a- 75        NODE'S TYPE: 11       C-INDEX= .01
NODE'S DESCRIPTION:CURING-I
-------------------------------------------------------------------------------
        NO.OF.PRE-N: 1    NO.OF.SUCC-N: 1       NO.OF.SUCC-RN: 0
        --------------    ---------------       ----------------
 NO          LABEL                LABEL         LABEL  NO.UNI
----         -----                -----         -----  ------
 1           a- 65                s- 85
-------------------------------------------------------------------------------
                     TYPE               MIN        MAX       M-MEAN      S.D
                     ----               ---        ---       ------      ---
STARTING TIME:        -                26.34      30.85      28.57      1.025
ESTIMATED DUR:   CONSTANT               7
*******************************************************************************


NODE'S LABEL:d- 95        NODE'S TYPE: 18       C-INDEX= 1
NODE'S DESCRIPTION:FRAMWORK IS FINISHED
-------------------------------------------------------------------------------
        NO.OF.PRE-N: 2    NO.OF.SUCC-N: 2       NO.OF.SUCC-RN: 1
        --------------    ---------------       ----------------
 NO          LABEL                LABEL         LABEL  NO.UNI
----         -----                -----         -----  ------
 1           s- 85                f- 100        1 2 - 1   1
 2           s- 90                s- 105
-------------------------------------------------------------------------------
                     TYPE               MIN        MAX       M-MEAN      S.D
                     ----               ---        ---       ------      ---
STARTING TIME:        -                36.06      40.37      38.04      0.866
TIME CONSTRAINT= 48              PROB.OF.ACHIEVING IT= 1
COST CONSTRAINT= 33600           PROB.OF.ACHIEVING IT= 1
*******************************************************************************


NODE'S LABEL:d- 160       NODE'S TYPE: 12       C-INDEX= 1
NODE'S DESCRIPTION:1ST-FIX IS FINISHED
-------------------------------------------------------------------------------
        NO.OF.PRE-N: 3    NO.OF.SUCC-N: 2       NO.OF.SUCC-RN: 2
        --------------    ---------------       ----------------
 NO          LABEL                LABEL         LABEL  NO.UNI
----         -----                -----         -----  ------
 1           s- 145               s- 165        1 6 - 1   1
 2           s- 150               s- 170        1 7 - 1   1
 3           s- 155
-------------------------------------------------------------------------------
                     TYPE               MIN        MAX       M-MEAN      S.D
                     ----               ---        ---       ------      ---
STARTING TIME:        -                46.18      50.76      48.04      0.978
*******************************************************************************


NODE'S LABEL:d- 265       NODE'S TYPE: 27       C-INDEX= 1
NODE'S DESCRIPTION:END
-----------------------------------------------------
NO.OF.PRE-NODES: 3
------------------
 NO        LABEL
----       -----
 1         s- 260
 2         f- 10
 3         f- 100
------------------------------
```

Figure (6-8)- Continued.

Figure (6-8) shows a sample of the detailed report on the hypothetical project activities and milestones. It is an output schedule produced by simulation. As shown on this figure, the program displays all the utility data for each node together with its criticality index, starting time, estimated duration, time and cost constraints with the probability of their achievement. In addition to that, the report includes a print-out of the distribution of the terminal node parameters (see figure 6-6).

6.4.3.2. Space Queue And Function Nodes Report :

The second option of the report module menu (table 6-4) loads a program called "SII.EXE". This program displays a menu shown on table (6-4-2).

Space Queue And Function Nodes Report Menu

1-Display Space Queue And Function Nodes Report.

2-Produce A Hard Copy Of The Space Queue And Function Nodes Report.

3-Return To Report Module Menu.

Table (6-4-2)

This type of report is shown on figure (6-9).

As shown on this figure, the program produces all the utility data for each node together with the idle time recorded by each Space Queue node, and the cost recorded by the BETWEEN nodes. For the ACCUMULATOR node, the program displays only its dependency logic as it accumulates the cost along the network and passes it to its succeeding node.

6.4.3.3. Resource Report :

The third option of the report module menu (table 6-4) loads a program called "LII.EXE" which produces a report on the labour resources. The fourth and fifth options load programs called MII.EXE and EII.EXE to produce reports on machinery and equipment resources respectively. This type of program has a main menu shown on table (6-4-3).

```
COPY OF SPACE QNODES DATA.
**************************

THE NETWORK HAS:  29  SPACE QNODES.
-------------------------------------



NODE'S NUMBER: 10                         NODE'S TYPE: 1
NODE'S DESCRIPTION:OVERHEAD-COST
-----------------------------------------------------------------
PRE-NODE'S NUMBER: 5                      SUCC-NODE'S NUMBER: 265
COST/TIME UNIT= 100
                          MIN          MAX          MEAN          S.D
                        -------      -------       ------       -------
COST PARAMETER:       6211.209     6863.631     6496.416      118.406
*****************************************************************


NODE'S NUMBER: 15                         NODE'S TYPE: 3
NODE'S DESCRIPTION:READY TO EXCAV-I
-----------------------------------------------------------------
PRE-NODE'S NUMBER: 5                      SUCC-NODE'S NUMBER: 25
                          MIN          MAX          MEAN          S.D
                        -------      -------       ------       -------
WAITING TIME:            0.000        0.000        0.000        0.0000
*****************************************************************


NODE'S NUMBER: 20                         NODE'S TYPE: 4
NODE'S DESCRIPTION:READY TO EXCAV-II
-----------------------------------------------------------------
PRE-NODE'S NUMBER: 5                      SUCC-NODE'S NUMBER: 30
                          MIN          MAX          MEAN          S.D
                        -------      -------       ------       -------
WAITING TIME:            4.840        7.152        5.974        0.5167
*****************************************************************


NODE'S NUMBER: 260                        NODE'S TYPE: 4
NODE'S DESCRIPTION:PAINTING FINISHED
-----------------------------------------------------------------
PRE-NODE'S NUMBER: 255                    SUCC-NODE'S NUMBER: 265
                          MIN          MAX          MEAN          S.D
                        -------      -------       ------       -------
WAITING TIME:            0.000        0.000        0.000        0.0000
*****************************************************************


NODE'S NUMBER: 100                        NODE'S TYPE: 2
NODE'S DESCRIPTION:ACC-COST
-----------------------------------------------------------------
NO.OF.NODES PRECEEDING ACC-NODE= 2        SUCC-NODE'S NUMBER: 265
*****************************************************************
```

Figure (6-9)- Space Queue And Function Nodes Report.

Resource Report Main Menu

1-Summary Report.

2-Detailed Report.

3-Return To Report Module Menu.

Table (6-4-3)

The summary report option has a separate menu shown on table (6-4-3-a).

Resource Summary Report Menu

1-List The Resource Categories In The Descending Order Of Their Idle Time Cost.

2-Produce A Hard Copy Of The List Of The Resource Categories In The Descending Order Of Their Idle Time Cost.

3-Return To Resource Report Main Menu.

Table (6-4-3-a)

Figure (6-10) shows this type of report on labour resources.

The first part of this report shows the number of resource categories with the number of Resource Queue nodes of the network for each category.

The second part displays the cost of the unit of resource/time unit, the mean and standard deviation values of the total idle time recorded for each resource category during the simulation, and finally the total cost of this idle time.

This report is produced after each simulation experiment to give the user the opportunity of primary evaluation of the output schedule in terms of resources and their idle time. Thus he can ask the program to produce a detailed report on each

COPY OF SUMMARY REPORT ON LABOUR RESOURCE.
****

THE NUMBER OF LABOUR RESOURCE CATEGORIES= 8

CATEGORY NO	NO.OF.QNODES
1	2
2	2
3	3
4	3
5	3
6	2
7	2
8	2

SEQ	CATEGORY NUMBER	NO.OF NODES	UNIT RATE /TIME UNIT	IDLE TIME MEAN	IDLE TIME S.D	MEAN VALUE I.T.(COST)
1	1	2	700	7.82	1.077	5470.987
2	4	3	200	13.00	0.096	2599.671
3	5	3	200	13.00	0.096	2599.671
4	3	3	200	12.00	0.007	2400.120
5	2	2	400	0.00	0.000	0.000
6	6	2	300	0.00	0.000	0.000
7	7	2	300	0.00	0.000	0.000
8	8	2	300	0.00	0.000	0.000

Figure (6-10)- Labour Resource Summary Report.

resource category that in relation to its recorded total idle time and its unit resource cost/time unit.

It is a useful report for the planner and for senior management, because it shows which resource is likely to be idle throughout the execution phase.

The second option of the menu is to produce a detailed report.

This option has a separate menu shown on table (6-4-3-b).

Resource Detailed Report Menu

1-Display Detailed Report And Schedule On The Resource.

2-Produce A Hard Copy Of A Detailed Report And Schedule On The Resource.

3-Return To The Resource Report Menu.

Table (6-4-3-b)

Figure (6-11) shows a sample of this report for the labour resource category one in the hypothetical project. This report displays summary information on the resource flow network including :

- The number of Resource Queue nodes.
- The cost of resource unit/time unit.
- The total idle time recorded by all the Resource Queue nodes of this resource category.
- The total cost of the idle time of this resource category.

The second part of this report displays detailed information on each of the Resource Queue node including:

- Its dependency logic.
- The idle time it recorded during the simulation.

COPY OF DETAILED REPORT ON LABOUR RESOURCE CATEGORY: 1
****

CATEGORY DESCRIPTION:FORMWORK CREW
THE NUMBER OF LQNODES= 2
UNIT RATE/TIME UNIT= 700

	MIN	MAX	MEAN	S.D
IDLE TIME :	5.29	10.03	7.82	1.077
IDLE TIME COST:	3702.97	7023.10	5470.99	753.927

COPY OF DETAILED REPORT ON THE QNODES OF LABOUR RESOURCE CATEGORY: 1
****

1 NODE'S NUMBER: 1
NODE'S TYPE IS:Q-MULTIPLE
PRE-NODE'S NUMBER: 25
PRE-NODE'S TYPE : 10

THE NUMBER OF SUCC-QNODES= 3

SEQ	SUCC-NODE'S NO	SUCC-NODE'S TYPE
1	45.	10.
2	50.	10.
3	2.	9.

	MIN	MAX	MEAN	S.D
IDLE TIME :	5.29	10.03	7.82	1.077

2 NODE'S NUMBER: 2
NODE'S TYPE IS:SINK
PRE-NODE'S NUMBER: 1
PRE-NODE'S TYPE : 8
THE NUMBER OF UNITS= 2

	MIN	MAX	MEAN	S.D
RELEASING TIME:	27.40	30.86	29.20	0.790

COPY OF SCHEDULE OF LABOUR RESOURCE CATEGORY: 1
****

NODE NO	NODE TYPE	NO.OF UNITS	PARA TITLE	PARA TYPE	MIN	MAX	M-L MEAN	S.D	C-I
45	ACT	1	STR-T		14.84	17.15	15.97	0.517	0.01
			E-DUR	BETA	8.00	14.00	10.00		
50	ACT	1	STR-T		19.67	22.21	21.00	0.586	0.99
			E-DUR	BETA	7.00	10.00	8.00		
2	SINK	2	REL-T		27.40	30.86	29.20	0.790	

Figure (6-11)- Detailed Report On Labour Resource Category One.

This part is very important for the planner. It guides him to the spot where this resource category is interrupted, so he can define which resource category halt the progress of the resource in question.

The third part of this report displays a schedule for the resource category. On this schedule, the starting time, the estimated time duration, and the criticality index of each of this resource activity is displayed. Also, the realization time of each of the SINK nodes is displayed as well to show when this resource category can be released from the site. This part of the report is very useful. It provides scheduling information to both the site manager and the foreman of the relevant trade.

The next chapter introduces a case study which demonstrates in detail how the model can be used in practice and its capability.

Chapter Seven

Secondary School In DAMASCUS "Case Study"

7.1. Introduction :

The final stage in developing any operations research technique is the validation of the model internally and externally.

A. Internal Validation :

This involves close examination of the internal logic and the structure of the model itself, and justification of the theory behind it. This has been demonstrated in previous chapters throughout the development phase of the model.

B. External validation :

This phase treats the model as a black box and examines the output of the model in terms of its validity as a solution to the problem in hand. For this phase, network techniques have always been a special case.

Theoretically the ideal way to test this type of model is to apply it to different types of project and examine its capability of modelling reality and predicting future events in real life situations.

The problem with this approach is the question of how many real life cases of each type of project should be considered to reach concrete conclusions?.

Obviously, even with a moderate number of cases and favourable conditions this test will take decades to finish and will cost a lot in resources.

Faced with this difficulty, people working in this area of research have adopted a more realistic approach. After finishing the development stage, they apply the model to a real life project. Throughout the execution phase, they compare the output of the model with the outcome of reality and assess difficulties. At the end of the test they draw a limited conclusion on the capability and limitation of the model, then they launch it for use in practice.

As the time passes, experience in the field reveals the shortcomings and improvement and refinement become a continuous process. This is exactly what has happened to the original versions of the network technique, namely C.P.M. and PERT.

The current work was faced with the following problems :

1-Since the model is based on simulation, it is practically impossible to apply it to a real life project without the availability of a software capable of handling the simulation process and its analysis. The development of the final version of the model and the required software took the author three years to finish. This alone consumed the time and the finance available to this work.

2-In order to demonstrate the capability of the model in handling the interaction between resources, the real life project should involve diversity of trades interacting with each other, and because of the time limit the start of the project should coincide with the finishing time of software development. Also, the author has to find an organization which has a project with the above features, and which is willing to co-operate all the way through from the start of the construction phase untill the end. Obviously , these conditions under the time constraint are impossible to obtain.

Faced with this situation , the author was left with two options :

1-The first option is to design a special case study or to use a suitable one from the textbook and assume all the necessary data to run the model. In this case, the test will be excessively artificial, and all the difficulties which may be encountered in the real life application will be avoided. As a result, the conclusion becomes meaningless in terms of the applicability and limitation of the technique in practice.

2-The second option, which is adopted for this work, is to select a real life project with the features mentioned earlier and before the start of its construction phase. Then collect the necessary data with the help of the people who are likely to be involved in the execution of the project. After finishing the development of the software, the data will be input to the model, detailed analysis will be done, and conclusions will be drawn concerning the application difficulties, the capability of the technique in modelling the site management's way of thinking, the flow of resources, and how the technique handles the imbalance between trades taking variability(see section 1.6.1) into consideration.

This chapter presents an extensive explanation on the method of operation of the model, the difficulties which may be encountered in practice, the capability, and interpretations of its output and analysis. All these are introduced through a real life project which is a secondary school building in DAMASCUS. The demonstration is presented in step-by-step fashion following the systematic procedures introduced in chapter five. All the drawings and figures related to this case study are compiled in the appendix.

7.2. Project Description :

The author visited DAMASCUS in the spring of 1985 after finishing the development of the first version of the model. He spent almost three months in collecting the necessary data for running the model and demonstrating its capability. Several state owned contracting companies were approached, including General Building Construction (G.B.C).

This company specializes in public buildings such as government departments, schools, and universities. The majority of its work is of measurement type contracts based on priced bills of quantities. It obtains its works through competitive bidding with other contracting companies. Several projects were considered, and finally the choice of a secondary school building was made.

The project is owned by the education authority of Damascus City Council, and the company at that time was awaiting the outcome of the bidding competition. The site is located in one of the suburbs of Damascus(40 km from the city centre), and covers 1400 square metres of land . Figures one to seven in the appendix show the site plan, the north and south elevation of the building, the plan of each floor, a cross section of the building, and the plan of the foundation and tie beams. The site consists of three-floor building surrounded by a footpath covered with tarmac. Adjacent to the footpath, there is a landscaped area separated from the neighbouring lands and external roads by a light concrete block boundary wall.

The basement floor has the school laboratory and library, the service room, and two toilets. The ground floor houses the entrance of the building, the reception, the headmaster office, the teaching staff room, four classrooms, and two toilets. The first floor consists of six classrooms, a coffee-bar, and two toilets.

The frame structure of the building is made of cast-in-place reinforced concrete elements. All walls and partitions are made of light concrete blocks and covered with plaster and paint. The walls and partitions of the laboratory, the service room, the coffee-bar, and all toilets are partially tiled, and the rest of their height is covered with plaster and paint. All floors including the roof and the stairs are fully tiled. All windows and entrance doors are made of aluminum frames with glass. External windows and doors in the basement are metal covered with paint. The elevations and the boundary wall are plastered with scratch layer covered with coloured mortar. Finally, the building is centrally heated and the entrances to the site are equipped with two-way metal gates.

7.3. The Company Practice :

At this point , it is necessary to introduce a brief idea on the company practice in planning and allocating its resources. This idea will justify the way which is adopted in the present case study to balance the required resources and achieve the detailed plan for the project.

The company relies on in-house resources for carrying out the majority of its operations. It subcontracts only a few specialized jobs for which it can not keep permanent staff. For managing its resources , the company has a central planning office which allocates all types of resources and move them between projects. This office is responsible for ensuring that the level of resources in the company is just enough to carry out its operations, and when the conditions do not justify any recruitment they subcontract part of the work to private firms. The company's experience in using C.P.M. is very limited. It depends on the size of the project, on occasion they use C.P.M., Bar Charts are used in other cases.

At the bidding stage, the planner with the co-operation of the estimator produces a pre-tender plan for the project. After winning the contract, this plan is modified, if necessary, to become a master plan.

The master plan serves as a guideline for the planning office. It provides rough estimates of the required amount of resources and the time at which they will be needed. Also, it serves as a guideline for the site management to conduct detailed planning for their work.

At the construction phase, the site management plan their work in detail on a monthly or three-monthly basis. At each period they put orders to the central planning office to allocate the required resources due to their plan and schedule. The planning office assigns priority to each project and allocates the available resources accordingly. This system of priority and manoeuvering results in several return visits to the same project by specific trades which in turn ensures full utilization of the available resources.

7.4. Project Breakdown Structure (P.B.S.) :

A P.B.S. chart for the project is shown in figure(8). Discussions with the estimator and planner revealed that the conduct of this phase in the company is informal, but they agree that the formal way is far better, as it provides a more clear review of all the items involved. While with the informal way, the only cross-checking facility they have relates to the drawings and bill of quantities.

As shown on figure(8), the project is divided into five workpackages : site set-up, substructure works, superstructure works, finishing works, and finally plan works. Each workpackage is subdivided into its functional elements and sub-elements. The detail stops at the sub-element level, which for this size of project is sufficient for the purpose of summary and detailed planning.

7.5. Project Master Plan :

To design a workable plan and work out project completion times, it is essential to define the type and level of the required resources. A formal Project Breakdown Structure is very helpful is this case, because it shows all types of works encountered in the project.

7.5.1. Resource Details :

Through experience over the years the company established a standard gang size or crew size with a standard make up for most of the commonly used resources. This makes the planner's and estimator's task relatively easy, because with a standard gang size productivity and in consequence time and cost estimates are more easily defined. With the help of the planner, site manager, and estimator two lists of the required resources are prepared, one for machinery resources shown on figure(9), and one for labour resources shown on figure(10). Each row on the list has detailed information on the particular type of resource.

For example: on figure(9) a site excavation crew consists of:

-One (J.C.B-4) front bucket and driver.

-Two lorries plus drivers.

-Two labourers.

and costs 2600 syrian pound a day. This cost is an all-in rate cost.

It is necessary to emphasis here that the idea of working out the cost of the crew per day is new to both planner and estimator, because the planner traditionally does not consider cost during the planning process, and the estimator conventionally uses man.hour or gang.hour as a base for estimating labour and machinery costs for each bill item.

In addition to these two lists the following three items of plant are required :

A-A static tower crane which will be installed on a concrete base by the north entrance of the building. The capacity of this crane is 500kg at the end of a 21m boom. Its purpose will be to unload and lift all the required materials for framework construction and to serve placing concrete operations.

B-A platform hoist of 500kg capacity will be installed by the south entrance of the building. This hoist will replace the tower crane after finishing the framework works. Its purpose will be to lift all finishing materials to different levels in the building.

C-A 200 litre mobile mixer for mixing mortar for blocklaying and finishing works, and mixing concrete for small backfilling jobs.

7.5.2. Contract Duration And Target Date :

The duration of this project as specified in the contract conditions is 50 weeks. In SYRIA there are six working days in a week and one day as a weekend holiday. Within these 50 weeks there are 22 days as national holidays. So the actual working days available for this project are :

$$(50)(6)-22=278 \quad \text{days.}$$

In his book[94], F.L.Harrison mentioned that, in order to compensate for the unforeseen conditions of the real world, 10-20% of the agreed contract duration should be considered as a buffer time when working out the target date. In the G.B.C. company the planner used to allow 10-15% of the agreed duration as a spare time. This depends on the size and complexity of the project. For the current project he allowed 10%, (278)(0.9)=250.2, and the target date is defined as 250 days.

7.5.3. Master Plan Structure And Completion Time:

At the time of data collection the master plan was already designed and analysed by the planner using a C.P.M technique with activity-on-node configuration. Figure (11) shows the plan network as it is designed with minor modifications. Each node in this figure has a number and abbreviated description of the activity it represents. All the nodes and arrows of the critical path are drawn with thick lines.

For this thesis the network was divided into sub-networks, each representing a stage in the project as conceived by both the planner and the site manager. As shown on figure (11), each sub-network is encircled with a closed line and marked with a letter to permit later reference. Milestone nodes were added to mark the start and the end of each sub-network, and to link this summary network with the detailed network. This addition does not affect the logic and the analysis of the network because they are dummy activities with zero time duration.

The type of work involved in each sub-network together with the level of resourcing and the time estimates as produced by the planner are summarized in table (7-1).

The outcome of the critical path analysis of this master network plan together with activities' estimated duration and their descriptions are listed in the table of figure (12) in the appendix. The information displayed on this table are self-explanatory. Milestone nodes appear in dark lines and letters, and the critical activities are marked with a star in the last column of the list.

7.6. Detailed Network Using The Model:

After drawing the master plan and defining the project completion time and the start and finish times of each stage of construction, the next stage of the planning process is to define the method of working in details. This is in order to design the structure of the detailed network and the flow network of each resource.

7.6.1. Detailed Method Statement:

With the co-operation of the site manager the following method of proceeding is defined:

1-Site Set-Up Works:

The work starts by clearing the site, then the surveying crew moves in to take off all site levels and define site boundaries and the necessary reference points. After the site is laid out, the excavation crew starts rough grading activity and removes the top soil and reduces the level to street level.

At this point site accommodation and temporary service work starts and the tower crane base will be built to install the crane in order to be ready for use.

Sub-network	Activity	Type of Work	Resource Involved	Time Estimate
A	5	It comprises all elements of workpackage (1) (fig-8), and involves the following type of work: -Site clearance and rough grade. -Site layout. -Site accommodation. -Tower crane installation. -Electrical works for temporary service. -Plumbing works for temporary service.	-Machinery resource(cat-1)(fig-9). -Surveying crew(fig-10). -Carpentry(cat-2)(fig-10). -T-crane crew(cat-5), 3 labourers(cat-21) (fig-10). -Electrical crew(cat-4) (fig-10). -One gang (cat-4) (fig-10).	16 Days
B	15	Excavate building and internal drainage works. It comprises part of the functional elements(1,2) of the workpackage(2)(fig-8), and has the following works: -Excavate building (reduce level). -Excavate for internal drainage. -Bedding and pipe laying (internal drainage). -Backfilling (internal drainage).	-Machinery(cat-1)(fig-9). -Machinery(cat-2)(fig-9). -3 gang crew(cat-4) (fig-10). -Machinery (cat-3)(fig-9).	16 Days

Table (7-1)

C	25	<u>Foundation works</u> It comprises the functional element(2) of the workpackage(2)(fig-8), and involves the construction of the retaining wall base and columns and tie beams bases which involves the following works: -Excavation. -Formwork and steel fixing. -Placing concrete. -Formwork dismantling. -Backfilling.	 -labour(cat-21)(fig-10). -lab(cat-6)(fig-10). -Machinery (cat-6)(fig-9). -Lab(cat-6)(fig-10). -Machinery(cat-3)(fig-9).	26 Days
C	30	<u>Framework In the Basement</u> It comprises functional elements(3,4) of w-package (2)(fig-8). This involves the construction of the retaining walls, columns, beams, slab stairs of the basement floor. -Formwork and steel fixing. -Placing concrete. -Formwork dismantling. -Backfilling to retaining wall. -Hardcore filling.	 -Lab(cat-7)(fig-10). -Machinery(cat-6,7)(fig-9). -Lab(cat-7)(fig-10). -Machinery(cat-4)(fig-9). -Machinery(cat-3)(fig-9).	41 Days
D	40	<u>Framework of ground floor.</u> It comprises the functional elements (1,2) of work-package(3)(fig-8), which involve construction of columns, salbs,beams,stair and includes the following sub-elements: -Formwork and steel fixing. -Placing concrete. -Formwork dismantling.	 -Lab(cat-7)(fig-10). -Machinery(cat-6,7)(fig-9) -Lab(cat-7)(fig-10).	32 Days

Table (7-1)-Continued.

E	50	<u>Framework of 1st floor.</u> -Same as activity 40	-Same as with activity 40	32 Days
F	60	<u>R.C.roof and entrances</u> It comprises the functional elements(1,2) of the work-package(3)(fig-8), and includes the following subelements: -Formwork and steel fixing. -Placing concrete. -formwork dismantling.	-Lab(cat-7)(fig-10). -Machinery(cat-6,7)(fig-9) -Lab(cat-8)(fig-10).	12 Days
G	70	<u>Blocklaying-Basement</u> It resembles functional element(5)(fig-8), and involves the blocklaying works of walls and partition in the basement.	-4 gang crew of labour (cat-10)(fig-10).	10 Days
G	75	<u>1st-fixing in the basement</u> It resembles part of the functional elements (1,2,3,4) of workpackage (4)(fig-8) and includes the following subelements: -Metal doors and windows. -Central heating. -Plumbing. -Wooden doors. -Electrical works.	-Lab(cat-12)(fig-10). -One gang crew Lab(cat-16) (fig-10). -One gang crew lab(cat-15) (fig-10). -One gang crew(cat-13) (fig-10). -2 gang crew (cat-11) (fig-10).	14 Days

Table (7-1)-Continued.

G	80	Plastering and tiling works in the basement floor. It comprises part of the functional elements(5,6) of the workpackage (4) (fig-8) and includes the following subelements: -Plastering walls and ceilings. -Tiling walls and floors.	 -8 gang crew Lab(cat-17) (fig-10). -8 gang crew Lab(cat-18) (fig-10).	18 Days
G	85	2nd-fixing works in the basement It comprises part of the functional elements (1,2,3, 4)(fig-8), and includes the following: -Metal doors and windows. -Central heating. -Plumbing. -Electrical works. -Wooden doors. -Glazing.	 -2 gang crew lab(cat-12) (fig-10). -1 gang crew lab(cat-16) (fig-10). -2 gang crew lab(cat-15) (fig-10). -2 gang crew lab(cat-11) (fig-10). -2 gang crew lab(cat-13) (fig-10). -2 gang crew lab(cat-19) (fig-10).	11 Days
G	90	Painting in the basement it resembles the functional element(7) of the work-package(4)(fig-8) .	-6 gang crew lab(cat-20) (fig-10).	9 Days

Table (7-1)-Continued.

H	100	Blocklaying in ground floor. -Same as activity (70).	-Same as with activity (70)	17 Days
H	105	1st-fixing works in the ground floor. -Same as activity (75) except that it involves aluminum windows instead of metal doors and windows	-2 gang crew Lab(cat-14) (fig-10).	12 Days
H	110	Plastering and tiling works in the ground floor. -Same as activity (80).	-Same as activity (80).	15 Days
H	115	2nd-fixing in ground floor. Same as activity (85) except it has aluminum windows and doors instead of metal.	-3 gang crew lab(cat-14) (fig-10).	17 Days
H	120	Painting in ground floor. -Same as activity (90).	-Same as activity (90).	9 Days
I	130	-Same as activity (100).	-Same as activity (100)	20 Days
	135	-Same as activity (105).	-Same as activity (105).	12 Days
	140	-Same as activity (110).	-Same as activity (110).	15 Days
	145	-Same as activity (115).	-Same as activity (115).	17 Days
	150	-Same as activity (120).	-Same as activity (120).	8 Days

Table (7-1)-Continued.

J	160	Blocklaying in the roof, entrances, and staircase. -It comprises the functional element(3) of the work-package(3)(fig-8).	-4 gang crew Lab(cat-10) (fig-10).	8 Days
J	165	1st-fixing in the roof, entrances, and staircase. It comprises functional elements (1,3,4)(fig-8) of the workpackage(4), and involves the following subelements: -Metal doors. -Aluminum doors and windows. -Plumbing. -Electrical works.	 -2 gang crew lab(cat-12) (fig-10) -2 gang crew lab(cat-11) (fig-10) -1 gang crew lab(cat-15) (fig-10). -2 gang crew lab(cat-11) (fig-10).	4 Days
J	170	Plasterting and tiling for roof,entrances and stairs -Plastering. -tiling.	 -6 gang crew lab(cat-17) (fig-10). -6 gang crew lab(cat-18) (fig-10).	16 Days
J	175	2nd-fixing in the roof, entrances, and stairs -Metal doors. -Aluminum windows and doors -plumbing. -Electrical works. -Glazing.	 -1 gang crew lab(cat-12). (fig-10). -3 gang crew lab(cat-14) (fig-10). -1 gang crew lab(cat-15) (fig-10). -2 gang crew lab(cat-11) (fig-10). -2 gang crew lab(cat-19) (fig-10).	4 Days

Table (7-1)-Continued.

J	180	<u>Painting in the roof</u> It comprises the functional element(7) of workpackage (4)(fig-8).	-2 gang crew lab(cat-20) (fig-10).	4 Days
J	185	<u>Painting for staircase and entrances.</u> -Same as activity (180)	-Same as activity (180).	6 Days
J	190	<u>Plaster to elevations.</u> It resembles part of the functional element(6) of the workpackage(4)(fig-8), and involves scratch layer.	-6 gang crew lab(17) (fig-10).	12 Days
J	195	<u>Clour mortar to elevation.</u> It comprises part of the functional element(6) of workpackage(4)(fig-8).	-3 gang crew lab(cat-17) (fig-10).	10 Days
K	205	<u>Boundary wall foundations.</u> It resembles part of the functional element(3) of workpackage(5)(fig-8), and involves the following: -Excavation. -Build foundations.	 -Machinery(cat-2)(fig-9). -Machinery(cat-5)(fig-9).	5 Days
K	210	<u>Blocklaying and gate fixing</u> -It comprises part of the functional element(3) of the workpackage(5)(fig-8),and includes the following: -Gate fixing. -Blocklaying.	 -1 gang crew(cat-12) (fig-10). -4 gang crew(cat-10) (fig-10).	12 Days

Table (7-1)-Continued.

K	215	Plaster to boundary walls. It involves scratch layer.	-2 gang crew(cat-17) (fig-10).	12 Days
K	220	Cloured mortar to boundary walls	-2 gang (cat-17)(fig-10).	8 Days
K	225	External drainage works. It resembles the functional element(1) of the work-package(5)(fig-8), and involves the following: -Excavation. -Bedding and pipelaying. -Backfilling.	-Machinery(cat-2)(fig-9). -3 gang crew(cat-4) (fig-10). -Machinery(cat-3)(fig-9).	10 Days
K	230	Tarmac laying and landscaping It comprises the functional element (2) of the work-package(5)(fig-8), and, involves the following: -Tarmac laying. -Landscaping.	-3 gang crew lab(cat-18) (fig-10). -10 labourer crew (cat-21) (fig-10).	10 Days
K	235	Clear site	-10 labourer crew (cat-21) (fig-10).	4 Days

Table (7-1)-Continued.

2-Substructure Works:

The excavation crew continues its activities and reduces the level of the building area to be ready for foundation works. After the level is reduced the excavation crew leaves the site and the drainage excavation crew moves in followed by the plumbing crew once the plumbing work of temporary service has been completed. After finishing the internal drainage works, the labour crew starts the excavation for column bases and levels the base of the retaining wall. At the same time the drainage excavation crew together with the plumbing crew continue their activities and start the external works.

After the column bases and the retaining wall base are excavated the formwork and steel fixing crew (labour category (6) figure (10)) starts working to construct the foundations and tie beams. At this point, the building area will be divided into two working zones:

Zone-I(ZI) covers the area between axis (1) and axis (8) on the plan (see figures 3,4,5,7).

Zone-II(ZII)covers the area between axis (8) and axis (13).

This division is done for the following reasons:

-To allow the release of enough working face to the formwork and steel fixing crew by manoeuvering between these zones. This will eliminate possible idle time.

-This division reduces the amount of plywood necessary for the framework works, because the formwork can not be dismantled for re-use before the concrete is fully cured. With this division, part of the formwork set will be left in one zone until the concrete is cured, while the formwork crew is working in the other zone. The formwork will be moved from one floor to another, and it is estimated that one set of formwork for one floor will be enough to conduct all the framework works in the project.

-To allow the deployment of different trades at the same time, in order that each trade will release enough workface for the next trade and so on.

The formwork and steel fixing crew (labour category (6)) will be enhanced because the amount of carpentry works will increase when the foundation work is finished, and this crew becomes under labour category(7)(see figure 10).

The formwork crew continues its activities and starts building the columns and walls in zone-I. Then the concrete crew will be called in to place concrete to columns and walls of zone-I. At the same time the formwork crew starts building the columns and walls in zone-II.

After the concreting activity in zone-i is finished, the columns and walls in this zone will be left to be cured, while the formwork crew continues in zone-II. After the formwork works in zone-II are finished, the formwork crew moves to zone-I to dismantle the formwork and starts building the formwork for the slab in zone-I.

The work progresses in this fashion, and the formwork in the same zone will be moved from one floor to another to be used again.

3-Superstructure Works:

The framework work progresses as explained in the previous paragraph until the framework works in the building are finished. The tower crane will be dismantled at this point, and replaced by hoist to serve the finishing trades.

4-Blocklaying Works:

The blocklaying crew will be deployed directly after the formwork on the ground floor is dismantled. This is to allow proper access to the basement floor to handle all the required materials for this trade. The blocklaying work starts at the basement and progresses from basement to ground floor, first floor, roof and entrances and to the boundary wall at the end.

5-First Fixing Works:

All the crews of the finishing trades which have first fixing works will be deployed directly after blocklaying work in the basement is finished.

6-Plastering Works:

The plastering crew starts its activities directly after the first fixing work is finished in the basement and progresses with its works vertically from one floor to another.

7-Tiling:

The tiling crew moves in directly to each part of each floor released by the plastering trade. Enough number of the plastering and tiling gangs should be available, because these two trades are expected to be the bottleneck in releasing enough of the workface for the trades which have second fixing works.

8-Second Fixing:

The relevant trade will occupy the workspaces directly after they are released by the tiling crew.

9-Painting And Glazing Works:

The crew of these two trades will move directly to the spaces released by the second fixing trades. The plastering work for the elevation is done by the plastering crew. This work starts after the first fixing work is finished in all the floors of the building including the staircase and entrances. The plastering crew will install the scaffolding. After the plastering works and the coloured mortar works are finished, the plastering crew will dismantle the scaffolding to release the space for laying tarmac for the footpath.

10-Boundary Wall:

The work starts directly after dismantling the tower crane.

11-Plan Works:

Tarmac laying is to be done by the tiling crew. It starts directly after the scaffolding is dismantled. Landscaping starts at the same time as the tarmac laying works.

7.6.2. The Structure Of The Detailed Network:

Before introducing the structure of the detailed network, it is necessary to mention that at the time of data collection the concept of function nodes (i.e. BETWEEN and ACCUMULATOR nodes) had not yet been developed. The site overhead cost and the operational cost of the tower crane and hoist were added to the total cost of the project. After developing the last version of the model the site overhead cost/day and the operational cost/day for the tower crane and the hoist were assumed. These costs were modelled in the network.

This assumption does not affect the cost of each individual activity, since these costs are originally added to the total cost of the project.

1-Sub-Network (A):

This sub-network represents the site set-up works. It includes activity (0,5 and 10) in the master network (see figure 11). Figure (13) shows the detailed network of this phase of the project. In this figure, node (0)(fig-11) which marks the start of the project is represented by node (2) which has the same function.

This node initiates the following nodes:

-Space Queue node(4), which represents the site as a space ready for surveying activities. It records the time during which the site is waiting for the surveying crew to start activity (10).

-Space Queue node(6), represents the site when ready for clearing activity, and waits for the excavation crew to be available. It receives the initial cost which is passed to it by node(2). This represents the cost of moving in. Node(6) passes this cost to node (15) when activity (15) can start.

-BETWEEN node(8), stores the overhead cost/day and records the time duration between the end of node(2) which is the start of the project and the realization of node(150) which marks the end of the current phase which includes the site set-up works. Then this node works out the total overhead cost of this period and passes the total to the network through node(150). Also, it collects statistics on this total cost.

Surveying and layout activity is represented by COMBINATION node(10). This node waits until both the space and the surveying crew become available. then it combines their availability and the activity takes place. The node records the starting time, works out the total cost and releases both the space and the surveying crew for the following activities. It channels the flow through the Space Queue nodes (20,25) and passes the total cost to Space Queue node (25).

Node(15) works with the same fashion. It receives the initial cost from the Space Queue node(6) and adds to it the total cost of clearing site activity, then passes the total cost to Space Queue Node (30). The flow continues in the same way through the network.

Node(6) works as a connection node. It combines the flow at its input side and passes the accumulated cost carried by its preceding nodes to the relevant succeeding node. It channels the flow to the Space Queue nodes (65, 70 and 75) which represent the availability of the workspaces for building the tower crane base, installing site accommodation and excavation for the temporary service.

Node(150) works as a milestone. It marks the end of the site set-up stage. It has AND logic as an input and FILTER-3 as an output. It waits until all its preceding nodes are realized, then it combines the necessary flow and accumulates all the cost carried by them. It collects statistics on its realization time and compares the realization time and the total cost passed to it with the time and cost constraints imposed on it, it then channels the flow through its succeeding nodes. It passes the total cost to the ACCUMULATOR node(155). This ACCUMULATOR node passes the accumulated cost at the end of each iteration to the TERMINAL node(2410). Also, Node(150) initializes the start of BETWEEN node (160) which represents site overhead cost between the end of site set-up work and the end of the project.

Node (110) represents the tower crane installation activity. It passes its total cost and the cost carried to it by the incoming flow to the Space Queue node (145). It also initiates the start of recording the operational cost of the tower crane (node 140).

This BETWEEN node (140) represents the time duration between the end of the tower crane installation and the start of dismantling it (activity 1010) and records the total operational cost for that period.

This phase (i.e. sub-network A) is linked to sub-network(B) by the Space Queue nodes (45, 135)(see figures 11,13 and 14), and to sub-network(F) by the BETWEEN node (140) (see figures 11,13 and 18).

2-Sub-Network (B):

It represents building excavation and internal drainage works. Figure (14) shows the detailed network of this phase. The Space Queue node (45) represents the availability of the building area for activity (165). After the level is reduced (activity (165)), node (165) releases the necessary spaces for conducting the internal and external drainage works.

These spaces are represented by the Space Queue nodes (170 and 175). It also releases the excavation crew. Node (220) marks the end of this phase. It passes the total cost of this sub-network to the ACCUMULATOR node (155), and channels the flow to the Space Queue nodes (225 and 230).

This sub-network is linked to sub-network (A) through the Space Queue node (45) (see figures 11,13 and 14), to sub-network (C) through the Space Queue nodes (225 and 230)(see figures 11,14 and 15), and to sub-network(K) through the Space Queue node (175) (figures 11,14 and 23).

3-Sub-Network (C):

Sub-network (C) represents the foundation works and framework works in the basement. Figure (15) shows the detailed network for this phase. The work starts by excavating the column bases and levelling the retaining wall base, and progresses as the figure shows.

A new type of node is used in this figure to represent the curing time for concrete. Nodes (285 and 290) represent this period for the column bases. These nodes start directly after the placing concrete activities are finished and without the need for waiting for the availability of the workspace and the availability of any type of resource. They use a NORMAL type of activity node.

As explained before, the NORMAL node receives the total cost which is accumulated by the flow preceding it, and passes it to the following node. Node (352) works as a connection point in the network. The NORMAL nodes (465 and 470) represent the primary curing period for the slabs in zones(I and II) of the basement.

This period is one day, which is the minimum technical period to allow the workers to walk on the top of the concrete slab. The other period which is labelled as a full curing time, is the time duration necessary for the concrete slab to become strong enough to bear the designed load. It means that after this period the formwork and the support can be dismantled.

So nodes (465 and 470) release workspaces for constructing the columns of the ground floor. The accumulated total cost carried by the incoming flow to the node (465) will be passed to node (485) which in turn will pass it to the following Space Queue node to be accumulated with other costs up to the end of this sub-network. Node (530) marks the end of this phase and passes the total cost of this sub-network to the ACCUMULATOR node (155). It also channels the flow to the Space Queue nodes (535 and 536).

This sub-network is linked to sub-network (B) through the Space Queue nodes (225 and 230)(figure 11,14, and 15), to sub-network (D) through the S.Q.nodes (475 and 480)(figures 11,15, and 16), to sub-network (F) through the S.Q.node (535)(figures 11,15 and 18), and to sub-network (G) through the S.Q.node (536)(figures 11,15, and 19).

4-Sub-Network (D):

This represents the framework works in the ground floor. Figure (16) shows the detailed network of this phase. On this figure all nodes are self explanatory. Node

(700) marks the end of this phase and passes the total cost of this sub-network to the ACCUMULATOR node (155).

This sub-network is linked to sub-network (C) through the S.Q.nodes (475 and 480) (figures 11, 15 and 16), to sub-network (E) through the Space Queue nodes (650 and 655) (figures 11,16 and 17), and to sub-network (H) through the S.Q.node (705) (figure 11,16 and 20).

5-Sub-Network (E):

It represents the framework works in the first floor. Figure (17) displays the detailed network of this stage. Node (870) marks the end of this stage and passes its total cost to the ACCUMULATOR node (155). It also channels the flow to the S.Q.node (875).

This sub-network is linked to sub-network (D) through the S.Q.nodes (650 and 655) (figure 11,16 and 17), to sub-network (F) through the S.Q.nodes (820 and 825) (figures 11, 17 and 18), and to sub-network (I) through the S.Q.node (875) (figures 11,17 and 21).

6-Sub-Network (F):

It represents the framework works in the roof and entrances. Figure (18) shows a detailed network for this part of the project. On this figure node (940) represents placing concrete to the roof slab. It initiates the need to replace the tower crane with a hoist (activity 960).

After installation, the hoist will be ready for immediate use. Node (960) initiates the operational cost of the hoist through BETWEEN node (990). Node (990) records the duration between the end of hoist installation (node 960) and the start of dismantling it (node 2010), and works out its total operational cost. Node (1006) works as a connection node and marks the end of the need for the tower crane on site. Node (1010) passes the total cost of installing the hoist and dismantling the tower crane together with the total operational cost of the crane to the ACCUMULATOR node (155).

Node (1020) marks the end of this sub-network and passes its total cost to the ACCUMULATOR node (155). This phase or sub-network is linked to sub-network (C) through the S.Q.node (535) (figure 11,15 and 18), to sub-network (J) through the S.Q.nodes (1025 and 1030) and through the BETWEEN node (990)(figures 11,18 and 22), and to sub-network (K) through the S.Q.nodes (1035,1040 and 1015), (figures 11,18 and 23).

7-Sub-Network (G):

(G) represents the blocklaying and finishing works in the basement floor. Figure (19) shows a detailed network for this stage. After the blocklaying activity is finished, node (1045) releases the necessary workspaces for all finishing trades which have first fixing works, and passes the total cost of blocklaying activity to the S.Q.node (1050).

Nodes (1125 and 1210) are connection nodes. They combine the incoming flows and channel them to the relevant succeeding nodes. Also they pass the total cost carried by the incoming flows to one of the following S.Qnodes. Node (1320) marks the end of works in the basement floor and passes the total cost of this stage to the S.Q.node (1325).

Node (1325) carries the total cost to be passed at the end of the iteration to the TERMINAL node (2410). It represents the basement floor as a place which is ready to be handed over, but it is waiting for the project to be finished.

This sub-network is linked to sub-network (C) through the S.Q.node (536), (figure 11,15 and 19), and to sub-network (J) through the S.Q.nodes (1145 and 1305) (figures 11, 19 and 22).

8-Sub-Network (H):

It represents the blocklaying and finishing works in the ground floor. Figure (20) displays a detailed network for this phase. The structure of this network is self explanatory. Node (1605) passes the total cost of this phase to the S.Q.node (1610) which signals that the ground floor is ready to be handed over but it is waiting for the project to finish.

This sub-network is linked to sub-network (D) through the S.Q.node (705) (figures 11,16 and 20), and to sub-network (J) through the S.Q.nodes (1430, 1590), (figures 11,20 and 22).

9-Sub-Network (I):

Sub-network (I) represents the blocklaying and finishing works in the first floor. Figure (21) shows the detailed network of this phase. Node (1890) passes the total cost to the S.Q.node (1895) which has the same function of the S.Q.node (1610) (figure 20).

This sub-network is linked to sub-network (E) through the S.Q.node (875) (figures 11, 17 and 21), and to sub-network (J) through the S.Q.nodes (1715 and 1875) (figure 11,21 and 22).

10-Sub-Network (J):

It relates to the blocklaying and finishing works in the roof, entrances, staircase and elevations. Figure (22) shows the detailed network for this phase. Activity (1970) marks the end of the need for the hoist on site. It initiates the

S.Q.node (1990) which signals that the hoist is ready to be dismantled. Node (2010) receives the total operating cost of the hoist from the BETWEEN node (990). It adds the cost of dismantling to it and passes the total to the ACCUMULATOR node (155). Node (2185) marks the end of works in the building and passes the total cost of this phase to the S.Q.node (2190). Space Queue node (2190) represents the building as ready to be handed over or occupied and passes the total cost of this sub-network to the TERMINAL node (2410).

This sub-network is linked to:

- sub-network (F) through the S.Q.nodes (1025 and 1030) and through the BETWEEN node (990) (figure 11,18 and 22),
- sub-network (G) through the S.Q.nodes (1145 and 1305) (figures 11,19 and 22),
- sub-network (H) through the S.Q.nodes (1430 and 1590) (figures 11,20 and 22),
- sub-network (I) through the S.Q.nodes (1715 and 1875) (figures 11, 21 and 22), and to
- sub-network (K) through the S.Q.node (2180) (figures 11,22 and 23).

11-Sub-Network (K):

This represents the boundary wall works and plan works. Figure (23) displays a detailed network for this stage. Node (2400) marks the end of this stage and passes its total cost to the S.Q.node (2405) which passes it to the TERMINAL node (2410).

This sub-network is linked to sub-network (B) through the S.Q.node (175) (figures 11,14 and 23), to sub-network (F) through the S.Q.nodes (1035, 1040 and 1015) (figures 11,18 and 23), and to sub-network (J) through the S.Q.node (2180), (figures 11,22 and 23).

Node (2410) represents the end of the project. It has an AND input logic which requires all the preceding nodes to be realized. Also it has FILTER-3 as TERMINAL logic which means that this node has time and cost constraints imposed on it.

This TERMINAL node is preceded by the following nodes :

-BETWEEN node (160), represents the site overhead cost/time unit and passes the total overhead cost to the TERMINAL node.

-ACCUMULATOR node (155), accumulating the cost of some phases of the project and passing these accumulated cost to the TERMINAL node (2410).

-Space Queue node (1325), represents the basement floor as a ready place to be handed over and passes the total cost of sub-network (G) (figure 19) to the end node.

-Space Queue Node (1610), represents the ground floor and passes the total cost of sub-network (H) to the end node (figure 20).

-Space Queue node (1895), represents the first floor and passes the total cost of the sub-network (I) (figure 21) to the end node.

-Space Queue node (2190), represents the end of work in the building and that the whole building is ready to be handed over. It passes the total cost of the sub-network (J) (figure 22) to the end node.

-Space Queue node (2405), represents the site as ready and all the work is finished in it. It passes the total cost of the sub-network (K) (figure 23) to the end node.

All the activities which are on the critical path (which is defined by the second run of the simulation) (this will be introduced later) appear on all figures in dark lines.

7.6.3. Resource Networks:

This section introduces the structure of the networks which represent the flow of the required resources. In designing the resource flow network, three types of nodes are used to model the idle state of the resource and the point at which it finishes its relevant activities.

They are: Single-successor Resource Queue node, Multi-successors Resource Queue node and SINK node. As mentioned earlier (section 7.5.1), seven categories of machinery/plant resource and twenty one categories of labour are required for the construction phase of the project (see figures 9 and 10 for their details).

7.6.3.1. machinery Resource Networks:

The make up and the details of each category of machinery are shown on figure (9). Figures (24 and 25) display the networks for all machinery resources.

1-Excavation Crew(fig-24-a):

This crew commences the start of the project via node (2). It remains at the R.Q.node (2) awaiting the start of activity (15). R.Q.node (2) is marked (m-1) to identify this type of resources (machinery resource category number one). It records the duration of time spent by the crew waiting for the availability of all the other inputs of activity (15). Also it collects statistics on the idle time in this location. When activity (15) becomes able to start, the crew leaves its idle state at R.Q.node (2) and moves to its first active state at node (15).

The crew will be retained by node (150) for the duration of site clearance. This is estimated by the user. When activity (15) is finished, the crew will be released to move to its second idle state (node-4). There it remains until activity (40) can start. It then moves to its second active state and so on. When activity (165) (reducing level) is finished, the crew can leave the site or join another type of resource to make up a new crew. This is represented by SINK node(8, m-1).

This node records the time at which the relevant resource finishes its activities, and collects statistics on this value.

2-Excavation Crew(drainage and boundary wall):

Figure (24-b) displays the flow network of this resource. Node (165), after the reducing level activity is finished, initializes the flow of this resource. When the excavation for the external drainage is finished (node 2195), this crew leaves the site (SINK node-6).

This crew is called back to the site by node(1020) which marks the end of the framework works in the project. It initializes the flow of this resource which stays at the idle state (R.Q.node-8) awaiting the start of the activity which has the highest priority in the rank of the activities following the R.Q.node (8).

When the conditions for starting activity (2270) are satisfied the crew moves from its idle state (R.Q.node-8) to conduct the excavation for the foundation of the north part of the boundary wall, and when this activity is finished the crew moves back to R.Q.node (8) to wait for activity (2275) to start and so on. If one of the nodes following the multi-successor Resource Queue node is a SINK node (as in this case), this node should be the last to be realized, because it represents the point at which the resource finishes its activities and is ready to leave the site.

3-Backfilling Crew(drainage and basement floor):

This network is shown in figure (24-c). This crew is deployed after the pipelaying activity for the internal drainage (node-200) is finished. It leaves the site at the SINK node (8,m-3) when the backfilling to the basement activity is finished.

4-Backfilling Crew(retaining wall):

The crew is deployed after dismantling the formwork in the basement floor (node-521) (see figures 15 and 24-d). It leaves the site at the SINK node (4,m-4).

5-Foundation Crew(boundary wall):

It is deployed after the excavation of the boundary wall(south part) is finished. Its network is shown on figure (24-e), and it is self-explanatory.

6-Concrete Crews(cat-6, and 7):

These two machinery resource categories are supplied by the central mixing plant of the company. Their make up is shown in figure(9) and their networks are shown on figures (25-f and 25-g).

As is shown in figure (25) each formwork and steel fixing activity initializes one of these crews (depending on the size of the concreting job), after placing the concrete, the crew leaves the site and is then called back when any formwork and steel fixing activity finishes and so on.

7.6.3.2. Labour Resource Networks:

The make up of all the necessary labour resource gangs are shown in figure (10). Figures (26 to 39) shows the structure of the networks of all the twenty one labour categories for the first and second runs of the simulation. On these figures, when the number of gangs which makes up the size of the crew changes along the network, a digit between bracket will appear on the top of each R.Q.node to represents the size of the crew at this point.

1- Surveying Crew(figure 26-a):

This is a one gang crew, initialized by the start node(2) and leaving the site at the SINK node(6,L-1).

2- Carpentry Crew(figure 26-b):

This is initialized by node(60) and leaves to join the formwork crew at the SINK node (4,L-2).

3-Electrical Crew For Site Service (figure 26-c):

The network is self-explanatory.

4-Plumbing Crew (D+S.service)(fig-26-d):

On this figure node(90) which represents excavation activity for the temporary service initiates one gang crew of this resource. After this gang finishes the plumbing activity for temporary service(node 120), node (120) initializes two more gangs and the size of the crew becomes three gangs, and continues its plumbing activities until the pipelaying is finished for external drainage (node 2215). These three gangs leave the site at the SINK node (12,L-4). As mentioned earlier the figure between brackets on the top of each R.Q.node and SINK node represents the number of gangs making up the crew.

5-Tower Crane Installation Crew (fig-26-e):

The network is self-explanatory.

6-Formwork And Steel Fixing (substructure-fig-26-f):

This crew is called in by node (235) after the excavation activity of the column bases is finished. When it moves to R.Q.node (6), it will wait there for the conditions of activity (305) to be satisfied, then it starts activity (305) and moves back to R.Q.node (6) again. The last activity following R.Q.node (6) is activity (325).

This crew will be enhanced with more carpenters and labourers after it finishes activity (350) and arrives at the SINK node (10, L-6). When this extra resource is added to it, this crew becomes labour category number seven(see figure 10 for their make up and cost/day).

7-Formwork And Steel Fixing (superstructure-fig-27):

This crew finishes its activities when activity (920) (dismantle formwork of roof slab) is finished. Then part of this crew will leave the site and the other part forms a new crew to dismantle all the formwork left in the building. This new crew is labelled as labour category number (8) (see figure 10).

8-Formwork Dismantling Crew (fig-28-a):

No further explanation is required for this crew.

9-Hoist Installation Crew (fig-28-b):

This crew enters via node (940) when the concrete activity to roof slab is finished. It installs the hoist and leaves the site. When the hoist is no longer needed on the site, this crew comes back to dismantle the hoist and leave the site at the SINK node (8,L-9).

10-Blocklaying Crew (fig-28-c):

The size of this crew is 4 gangs (see figure 10). It is initialized by node (700) when the framework work in the ground floor is finished (see figure 16). This is in order to provide proper access to the basement to enable materials handling for blocklaying activities. It leaves the site when the blocklaying activities for the boundary wall are finished (SINK node 16,L-10).

11-Electrical Works Crew (fig-30-a):

This crew consists of 2 gangs. The composition of each gang is shown in figure (10). It commences directly after the blocklaying activity in the basement is finished (node-1045). It achieves all the first fixing activities and leaves the site at the SINK node (10,L-11). It is called in again by node(1210) after the tiling activities in the basement are finished (see figure 19). It achieves all its second fixing activities in the project and leaves the site at the SINK node (18,L-11).

12-Metal Windows And Doors Crew (fig-30-b):

A crew of 2 gangs is initialized by node (1045) to conduct the first fixing activities in the basement and leaves the site at the SINK node (4,L-12). The crew of the same number of gangs is called in by node (1900) (blocklaying to the roof) and moves to its idle state at the R.Q.node (6). After these two gangs achieve the first fixing activity in the roof (1920) and the second fixing activity in the basement, one of them leaves the site at the SINK node (8,L-12) and the other stays to complete activities (1995, 2345 and 2355), then leaves the site at the SINK node (14,L-12).

13-Wooden Doors Crew (fig-30-c):

A one gang crew is deployed to achieve the first fixing activities, and a 2 gang crew is deployed to achieve the second fixing activities. The structure of its network is self-evident.

14-Aluminum Windows And Doors Crew (fig,32-a):

A two gang crew is initialized after the blocklaying activity in the ground floor is finished. This crew achieves the first fixing activities and leaves the site at the SINK node (8,L-14).

A three gangs crew is called in after the tiling activities in the ground floor are finished (node-1495) (see figure 20), to achieve the second fixing activities and leave the site at the SINK node (16, L-14).

15-Plumbing Crew (fig,32-b):

A crew of one gang is deployed to achieve the first fixing activities and leaves the site at the SINK node (10,L-15). A two gangs crew is used to achieve all second fixing activities except the plumbing activity in the roof which is done by a single gang.

Again the network for this crew is self-explanatory (fig, 32-b).

16-Central Heating Crew (fig,32-c):

It is a one gang crew which is deployed directly after the blocklaying activity in the basement (1045) is finished. This crew is assumed to finish all first and second fixing activities continuously and leave the site at the SINK node (14,L-16).

17-Plastering Crew (fig-34):

This crew consists of 8 gangs divided into 3 gangs. Each of these is assigned a set of plastering activities in the project, and each leaves the site at a different point in time. This crew is initialized by node (1125) when the first fixing activities in the basement are finished (see figure 19).

The network on figure (34) shows the flow of each group and their leaving points. The structure of this network is self-explanatory.

18-Tiling Crew (fig-36):

This crew consists of 8 gangs also of 3 gangs. Each group of this crew is initialized at different points in the network. Group(1) consists of 2 gangs. It is deployed after the plastering activity in the toilet in the basement is finished. It completes the tiling activities in the toilets of all floors and leaves the site at the SINK node (20,L-18).

Group (2) consists of 3 gangs, its flow is self-explanatory. Group (3) consists of 3 gangs, it is assigned the tarmac laying activity to the footpath in addition to the tiling activity in part of the basement and in all areas of the ground floor, entrances and staircase.

19-Glazing Crew (fig,38-a):

It is a 2 gang crew and initialized by node(1860) after the second fixing activities in the first floor are finished. This is to provide enough workfaces to this crew (fig-21). Its network is self-explanatory.

20-Painting Crew (fig-38-b):

It is a 6 gang crew initialized by node (1290) after the second fixing activities in the basement are finished (see figure 19). It flows as shown on figure (38-b) and when it finishes the painting activity in the first floor (node 1880), four gangs of this crew leave the site at the SINK node (10,L-20), and 2 gangs stay to achieve the painting activity in the roof, entrances and the staircase (nodes 2040 and 2115), and leave the site at the SINK node(14,L-20).

21-Labourer Crew (fig-38-c):

The structure of the network of this crew is self-explanatory.

7.7. Time And Cost Estimates:

During the process of preparing the detailed network of each phase of the project, and based on the detailed drawings and bill of quantities, the quantity of each type of material required for each activity is defined. This includes the wastage allowance which is assumed by the project estimator. Also with the help of the estimator, the labour and machinery content of each activity in terms of man hours and machine hours are defined.

7.7.1. Time And Cost Targets:

The quantity of each type of material involved in each activity is multiplied by the relevant all-in-rate cost/unit which is defined by the estimator to work out the total cost of material for each activity. Also the labour and machinery contents are multiplied by the all-in-rate cost/unit to arrive at the total cost of labour and machinery resource for each activity.

For each phase of the project the total cost of all the activities involved are added together to work out the total estimated cost of the phase. This total cost is considered as a target cost which means that the construction cost of the phase should not exceed this value. This value is imposed on the milestone which marks the end of the phase and is considered as a cost constraint in the detailed network. All the milestones in the master and detailed networks are listed in a table shown in figure (40).

In this table the second column displays the node's number of each milestone as it is represented in the master network. The third column shows the node's number of the same milestone as it is represented in the detailed network. Columns five and six display the early and late realization times of each milestone as they are defined by the C.P.M analysis of the master plan. Column seven displays the estimated total cost of each phase of the project as it is defined and explained above.

Node (245) in row (12) on the table represents the end of the project. Its realization time as it is defined in the master plan is 245 days, and its target cost which is £2,490,000 represents the total cost of the project as a whole, as estimated by the estimator when bidding for the project.

This total cost includes the estimated site overhead cost and the total operating costs of the tower crane and hoist. The milestone which is on the critical path is marked with a star in column eight in the table (figure 40). The first five columns of the table on figure (41) display the same information for milestones in the detailed network. Column four of this table displays the late realization time of each milestone as it is defined by C.P.M analysis.

This value is considered as a target date for the phase it represents. It is imposed on the milestone in the detailed network as a time constraint. The rest of the information in this table will be explained later in the text.

As mentioned earlier the concept of BETWEEN and ACCUMULATOR nodes was not ready at the time of data collection, and the total cost of the site overhead and the operating cost of the tower crane and hoist are added to the total estimated cost of the project. When the final version of the model is developed, the site overhead cost/time unit and the operational cost/time unit for the tower crane and hoist are assumed and modelled in the detailed network. The values of these costs are listed in a table on figure (42).

7.7.2. Activity Time And Cost Estimates:

When the resource network of each required resource is designed and drawn (figures 24 to 39), and the amount of each resource is defined, it is possible to define the full logic of each activity (i.e. its preceding and succeeding nodes), and estimate its time duration and variable cost. Detailed Planning is usually left to the site management. In estimating the time duration the site manager relied on the productivity record of the trades involved, on his judgement of the difficulty of the work and its location and the make up of the crew which will be made available for the work.

A special effort was concentrated on obtaining data with the same quality as that which people in the company rely on and use. So the site manager and the planner were asked to provide time estimates for each activity. This step was faced with the following difficulties:

1-Since both the site manager and the planner use bar chart and traditional C.P.M techniques for planning, they are used to the idea of one point estimates. They experienced some difficulty when they switch from one point estimates to two or three, they loose the sense of consistency. In other words, their estimates for the same type of work in different parts of the project are inconsistent when they use two or three point estimates.

2-The author has to make sure that these estimates include only the variability caused by the difficulty of the work and its location and are not mixed with the variability caused by other factors such as the late arrival of materials or machinery breakdown which are accounted for when working out the target date. Throughout the process of producing the time estimates, the site manager and the planner showed the following attitudes:

-When the amount of work involved in the activity in question is relatively small, they tend to produce one point estimates especially when the type of work is easy to carry out. This one point estimate is represented as a constant value in the model.

-When the volume of work is moderate in size they provide two points estimates (minimum and maximum values), and the range between these two values depends on the type of work and the expected difficulty as conceived by the site manager and the planner.

-When the volume of work is relatively large they produce three point estimates (minimum, most likely and maximum values), and in two different configurations:

a-The most likely value is closer to the minimum value. They produce this type of estimate when they have confidence regarding the expected difficulties.

This is expected because the site management usually does not like to commit themselves to very optimistic minimum value, they usually tend to provide a minimum value closer to the most likely.

For this type of estimate a Beta or triangular distribution is assumed in the model.

b-The most likely value is in the middle of the range. They tend to provide this type of estimate when they are not sure about the difficulty of the work in question. Also when the resource involved is sharing the same workspace with other trades and resources.

This type of estimate is represented by a normal distribution bounded at the minimum and maximum values and the standard deviation is worked out to be equal to 1/6 of the range.

The final stage of the data collection is to estimate the cost of each activity in the detailed network.

The total cost of the activity consists of two parts : fixed and variable costs. The fixed cost consists of the total cost of all types of materials involved in the activity (material cost is considered fixed because it is not related to activity time duration). This type of cost is already defined in section (7.7.1). The variable cost consists of all costs related to the time duration of the activity. It comprises the cost of all resources involved in the activity in addition to the site overhead cost.

Since the site overhead cost and the operating costs of both the tower crane and hoist are shared by all the activities in the project they are modelled separately as explained earlier. So the variable cost of each individual activity is worked out as equal to the cost/day of one gang of the involved resource multiplied by the crew size defined in the resource network (see figures 9,10 and 24 to 39).

The resultant value represents the variable cost of the activity per time unit, and in this case study it is the cost/day.

7.8. Data Input:

At the first stage the summary data on the structure of the network is defined and fed to the program. This includes the following:

-The number of the activity and milestone nodes and the number of the Space Queue nodes in the main detailed network. These are obtained from the network drawings shown on figures (13 to 23).

- The number of labour and machinery resource categories. These are already defined when a decision is made regarding the detailed method of working.

-The number of the Queue and SINK nodes representing the flow of each resource category. This is obtained from the resource network of each category (figures 24 to 39).

At the second stage, the logic controlling each type of node in the network is defined, then all the nodes together with their utility data (i.e. time duration and cost parameters) are arranged in three separate lists (this is to ease the process of inputting data to the software):

1-Activity and milestone list:

This list contains the logic and the utility data of all the nodes representing the project activities and milestones in the network. For each node this includes:

- -The number and types of nodes preceding and succeeding it both in the main detailed network and in the networks of involved resources.
- -The type and parameters of its estimated time duration.
- -Its fixed and variable cost and in the case of milestone nodes this involves the time and cost constraints imposed on it as applicable.

After this list is prepared the data are fed to the program.

A sample of this type of input can be explained using the information displayed on figure (81). On this figure node (a-10) represents site layout activity. This activity is preceded by one Space Queue node (4) and succeeded by two Space Queue nodes (20 and 25) in the main network (see figure 13). This information is shown on the second and third column under the node's description on figure (81).

The letter S stands for Space Queue node and the number represents the node's number in the network. The resource involved in this activity is the surveying crew. Its flow is represented by the resource network shown on figure (26-a). In this network activity (10) is preceded by the Resource Queue node (2,L-1) and followed by the Resource Queue Node (4,L-1) (figure 26-a).

This information is shown on the fourth and fifth column in figure (81). The fixed cost of this activity is £100, and its variable cost/day is equal to the cost of the surveying crew/day which is £250 (see figure 10). The estimated time duration is constant and equals one day. All this information is clearly shown on figure (81).

2-Space Queue node and Function node list:

It contains the logic and the cost parameter (as applicable) of all the Space Queue nodes and Function nodes in the network. Figure (82) shows a sample of this type of information as it is input to the program. On this figure the Space Queue node (4) represents the site as a space ready for surveying. It is preceded by node (2) which represents the start of the project and followed by node (10) which represents the site layout activity (see figure 13).

The BETWEEN node (8) represents the site overhead cost from the start of the project till the end of site set-up works. It is preceded by node (2) and succeeded by the milestone node (150) (figure 13). The overhead cost/day which this node represents is equal to £200/day. This information is self-explained on figure (82).

3-Resource Node Lists:

One list is prepared for each resource category. Each list contains the following:

- -The resource category description, the number of Queue and SINK nodes representing its flow in the network, and the cost/day of one gang of its crew.
- -The logic controlling each of the Queue and SINK nodes including the number of gangs arriving at each SINK node.

Figure (79) shows the data input of the machinery resource category one, which is the excavation crew for site and building area. On this figure, the first part shows summary information of this resource. The second part displays detailed data on the queue and SINK nodes representing its flow in the network (see figure 24-a).

The Resource Queue node (4) which is a single-successor Queue node is preceded by node (15) (clear site) and succeeded by node (40) (rough grade) (see figures 24-a and 79). The SINK node (8) represents the point at which the excavation crew leaves the site. It is preceded by node (165) (reduce level) and the crew size is equal to one gang (figures 24-a and 79).

7.9. Simulation And Analysis (first run):

After all the data are fed to the program the simulation is run for 100 iterations. This number is considered to be enough to get reasonable statistics for each node's parameter and project completion time and cost.

7.9.1. Milestone Summary Report:

Figure (43) shows a print-out of a summary report on the milestones and the project TERMINAL node. To ease the discussion this information together with the realization time statistics and other parameters are arranged in a table shown on figure (41). In this table each row displays the data for one milestone.

The top part under columns (6 to 12) shows the output of the current simulation run, and the bottom part shows the output of the second simulation run which will be introduced later. Columns (6 to 9) display the realization time statistic. Columns (10 and 11) display the probability of achieving the time and cost target respectively. Column (12) shows the probability of the milestone being on the critical path.

In this simulation run, the mean realization time of milestone (150) (see figures 13 and 41) is 19.26, and its minimum realization time is 17.65 which exceeds its target time. So the probability of achieving its target is zero. As shown on figure (41) the probability of achieving its cost target is 0.48, and its criticality index is zero which means that this milestone has never been on the critical path during this simulation run. Milestone (220) which marks the end of site and building excavation has time and cost constraints equal to 32 days and £40800 respectively.

The output of the current simulation run (figure 41) shows that its mean and maximum realization time are 25.67 and 27.33 days, and the probability of achieving its target time and cost are 1.0 and 0.94 respectively. This milestone is always on the critical path because its criticality index equals unity. The TERMINAL node (2410) (see figure 23) represents the end of the project and collects statistics for project completion time and cost. These statistics are shown in figures (44,45,46 and 47).

Figure (44) shows that in this run the project completion time lies between 257.76 and 272.97 days. So with the current arrangement and amount of resources, the target date can not be achieved. Figure (45) displays PDF (probability distribution function) and CDF (cumulative distribution function) of the project net cost. This figure shows that the project will cost between £2,410,055.5 and £2,441,732.2, and this net cost is less than its target cost, so the probability of achieving the target cost is unity. Figure (46) shows PDF and CDF of the total cost of the idle time of all resources involved.

The information on this figure reveals how serious the idle time cost is. The mean value of this cost is £275,560.31 which represents almost 11% of the project target cost. Figure (47) displays the PDF and CDF of the project total cost. On this figure the project total cost will be between £2,666,264 and £2,737,402 which exceeds the target cost. This is caused by the cost of the idle time of the resources involved.

7.9.2. Activity Summary Report:

Figure (48) displays a list of all project activities in the order of their criticality index. This information is used to mark the critical activities in the resource network to be given an attention when balancing the resources. This will be expanded later.

7.9.3. Resource Summary Reports:

Figure(49) displays a print-out of a summary report on labour resources involved in the project. The first part of this report lists all labour resource categories with the number of Queue and SINK nodes representing their flow in the resource network. The second part lists these categories in the descending order of the total cost of their idle time.

In this part, column four shows the cost/day of one gang or crew of the relevant labour category. Columns five and six show the mean value and standard deviation of the total idle time of the relevant category in gang or crew days, and the last column shows the mean value of the cost of the total idle time. As is shown on this figure, ten out of twenty one categories have recorded a considerable amount of idle time.

Figure (50) shows the same type of information for the machinery resources. It is clear all the machinery resource categories did not experience any idle time and the continuity of work for all of them has not been interrupted at all.

7.9.4. Resource Detailed Report:

Figure (51) displays a print-out of this type of report for the tiling crew (labour category-18). The first part of this report produces summary information on the resource category in question. This includes statistics of the total idle time and its cost. The second part displays a record of the idle time recorded by each Queue node representing the flow of this resource category in its network.

7.10. Resource Balancing:

This phase involves two steps:

-Study and analyse the flow of each resource category which recorded an idle time. This is in order to find out which category or categories interrupted the flow of the resource in question.

-Consider the options available and decide on an action or combination of actions which are likely to eliminate all or the majority of the idle time.

7.10.1. Resource Flow Study And Analysis:

Figure (49) lists the labour categories in the descending order of their idle time cost. The study and the analysis of each category follows the same order to pinpoint the bottleneck category or categories.

1-Tiling Crew(lab,cat-18):

The detailed report of this resource (figure 51) shows that it recorded an average total idle time of 421.97 gang days with an average total cost of £63,295.48. Close study of this report reveals the following:

-The Queue nodes 8, 12 and 18 recorded average idle times of 6.76, 45.13 and 35.52 gang days respectively.

The tiling crew is halted at these Queue nodes awaiting the starts of activities 1465, 1470 and 1475 (see figure 36).The starts of these activities are prevented by the lack of the availability of the workfaces 1435, 1440 and 1445 (see figure 20) which are to be released by the plastering activities.

-The Queue nodes 14, 10 and 16 recorded average idle times 29.43, 121.25 and 39.65 gang days respectively.

The tiling gangs at these nodes are halted while awaiting the starts of the activities 1750, 1755 and 1760 (see figure 36). The starts of these activities are awaiting the release of the necessary work locations which are controlled by the plastering activities 1720, 1725 and 1730 in the first floor (see figure 21).

-The Queue node 24 recorded an average idle time of 60.68 gang days awaiting the start of the tiling activity 2085 (see figure 36) which follows the finish of the plastering activity 2075 (see figure 22).

-The Queue node 28 recorded an average idle time of 83.55 gang days awaiting the start of the tarmac laying 2250 (see figures 23 and 36). The start of this activity requires the dismantling of the scaffolding to be finished (activity 2170) (see figure 22).

In summary the flow of the tiling crew is interrupted by the plastering labour resource.

2-Painting Crew (lab,cat-20):

Figure (53) displays a detailed report on this labour category. The painting crew recorded an average total idle time of 205.53 gang days with an average cost of £30,830.01. The detailed report (figure 53) shows the following:

-The Queue node 4 recorded an average idle time of 153.11 gang days. The gangs are halted at this node awaiting the start of the painting activity 1595 (see figure 38-b).

The start of this activity is halted by the release of the workface which is controlled by the end of the second fixing works in the ground floor (node 1575 figure 20).

-The Queue node 6 recorded an average idle time 52.43 gang days. The crew at this node is halted awaiting the start of the activity 1880 (see figure 38-b) which is controlled by the end of the second fixing activities in the first floor (node 1860 figure 21).

So the painting crew is interrupted by the second fixing trades in the ground and the first floor.

3-Metal Doors And Windows Crew(lab,cat-12):

Its detailed report is shown on figure (55). This resource recorded an average total idle time of 116.05 gang days with an average cost equal to £23,210.18. All this idle time is recorded by the Queue node 6 (see figure 30-b). The crew is halted there awaiting the start of the activities 1255, 1920 and 1995 (see figure 30-b).

The start of activity 1255 is controlled by the finish of the tiling activities in the basement floor (node 1210 figure 19). The start of the activity 1920 is controlled by the finish of the blocklaying activity 1900 in the roof (see figure 22). The start of the activity 1995 is controlled by the tiling activity 1970 in the roof (see figure 22). So this labour category is interrupted by the blocklaying crew and the tiling crew.

4-Electrical Works Crew (lab,cat-11):

Figure (57) shows that this crew recorded an average total idle time of 70.71 gang days with an average cost of £21,213.36. A close look at this figure reveals the following:

-The Queue nodes 4 and 6 recorded average idle times equal to 6.39 and 13.14 gang days.

The gangs are halted at these Queue nodes awaiting the starts of the first fixing activities 1360 and 1645 in the ground floor and first floor (see figure 30-a). The starts of these activities are controlled by the finish of the blocklaying activities 1330 and 1615 in the ground and first floor (see figures 20 and 21).

-The Queue nodes 12 and 14 recorded average idle times equal to 30.02 and 15.42 gang days respectively awaiting the starts of the second fixing activities 1525 and 1810 in the ground and first floor (see figure 30-a). The start of these activities is controlled by the finish of the tiling activities in the ground and in the first floor (nodes 1495 and 1780 in figures 20 and 21).

-The Queue node 16 recorded an average idle time equal to 5.74 gang days awaiting the start of the second fixing activity 2005 in the roof (figure 30-a). The start of this activity is controlled by the finish of the tiling activity 1970 in the roof (figure 22).

So the flow of the electrical works crew is interrupted by the blocklaying crew when conducting its first fixing activities and by the tiling crew when conducting the second fixing activities.

5-Wooden Doors Crew(lab,cat-13):

Its detailed report is shown on figure (59). This resource category recorded an average total idle time of 101.45 gang days with an average cost equals £20,289.88.

This report reveals the following:

-The Queue node 6 recorded an average idle time of 11.31 gang days awaiting the start of the first fixing activity 1665 in the first floor (figure 30-a). The start of this activity is controlled by the finish of the blocklaying activity 1615 in the same floor (figure 21).

-The Queue node 12 recorded 69.66 gang days awaiting the start of the second fixing activity 1545 in the ground floor which is controlled by the end of the tiling activities in the same floor (node 1495 figure 20).

-The Queue node 14 recorded 20.48 gang days awaiting the start of the second fixing activity 1830 in the first floor which is controlled by the end of the tiling activities (node 1780 figure 21).

So the wooden doors first fixing activities are interrupted by the blocklaying crew and the second fixing activities are interrupted by the tiling crew.

6-Central Heating Crew (lab,cat-16):

Figure (61) shows that the average total idle time recorded by this category is 45.34 gang days with an average cost of £18,134.53. Also it shows the following:

-The Queue nodes 4 and 6 recorded 0.36 and 7.56 gang days as idle time. The crew is halted at these nodes awaiting the start of the first fixing activities 1365 and 1650 in the ground floor and in the first floor (figure 32-c).

The start of these activities is controlled by the finish of the blocklaying activities 1330 and 1615 in the same floor (figures 20 and 21).

-The Queue nodes 10 and 12 recorded average idle times equal to 23.35 and 14.06 gang days respectively.

The crew is halted at these nodes awaiting the start of the second fixing activities 1530 and 1815 in the ground floor and in the first floor (figure 32-c). The start of these activities is controlled by the finish of the tiling activities in both the ground and first floor (nodes 1495 and 1780(figures 20 and 21)).

So the first fixing activities of this labour resource are interrupted by the blocklaying crew and the second fixing activities by the tiling crew.

7-Plastering Crew (lab,cat-17):

Figure (63) reveals that the plastering crew recorded an average total idle time of 115.86 gang days with an average cost of £17,379.4.

-The Queue nodes 8 and 12 recorded an average idle times equal to 15.89 and 14.83 gang days respectively.

The gangs are halted at these nodes awaiting the start of the activities 1435 and 1440 (figure 34). The start of these activities is controlled by the end of the first fixing works in the ground floor (node 1410)(figure 20).

-The Queue nodes 10 and 14 recorded 51.65 and 32.11 gang days respectively. The gangs are halted at these nodes awaiting the start of the plastering activities 1725 and 1720 in the first floor (figure 34). The start of these activities is controlled by the end of the first fixing works in the same floor (node 1695)(figure 21).

So the flow of the plastering crew is interrupted by the first fixing trades.

8-Plumbing Crew (lab,cat-15):

Figure (65) shows that this crew recorded an average total idle time of 107.27 gang days with an average cost of £16,089.96.

-The Queue nodes 4 and 6 recorded 4.4 and 14.36 gang days respectively.

The gangs are halted at these nodes awaiting the start of the first fixing activities 1370 and 1655 in the ground floor (figure 32-b). The start of these activities is controlled by the blocklaying activities 1330 and 1615 in the same floors (see figures 20 and 21).

-The Queue nodes 14 and 16 recorded 62.73 and 24.74 gang days respectively awaiting the start of the second fixing activities 1535 and 1820 in the ground and in the first floor (figure 32-b).

The start of these activities is controlled by the finish of the tiling activities in the same floors (nodes 1495 and 1780)(figures 20 and 21).

-The Queue node 20 recorded 1.04 gang days awaiting the start of the activity 2000 (figure 32-b) which is controlled by the tiling activity (1970) in the roof (figure 22).

So the first fixing activities of the plumbing crew are interrupted by the blocklaying crew and the second fixing activities by the tiling crew.

9-Aluminum Windows And Doors Crew (lab,cat-14):

Figure (67) shows that this crew recorded 67.14 gang days with an average cost of £10,071.181. Also it shows the following:

-The Queue node 4 recorded 30.02 gang days awaiting the start of the first fixing activity 1660 (figure 32-a) which is controlled by the blocklaying activity 1615 (figure 21).

-The Queue node 11 recorded 37.12 gang days awaiting the start of the second fixing activity 1825 (figure 32-a) which is controlled by the end of the tiling activities in the first floor (node 1780)(figure 21).

So the first fixing activities of this labour category are halted by the blocklaying crew and the second fixing activities by the tiling crew.

10-Blocklaying Crew (lab,cat-10):

Figure (69) shows that this resource category recorded 5.02 crew days at a cost of £3,010.58. All this idle time is recorded by the Queue node 6. The gangs are halted at this node awaiting the start of the blocklaying activity 1615 in the first floor (figure 28-c).

The start of this activity is controlled by the end of the framework works in the first floor (node 870) (figure 17). So this small idle time is caused by the formwork and steel fixing crew.

7.10.2. Course Of Action:

After studying the flow of each resource category which recorded an idle time during the simulation. The next step is to decide on one or a combination of actions which can provide a continuity of work for each resource and eliminate the causes of interruption.

1-Blocklaying Crew (lab,cat-10):

As shown in section (7.10.1. part-10) this resource category has recorded an average idle time of 5.02 crew days which is caused by the formwork and steel fixing trade.

Also this resource interrupted the first fixing activities of the finishing trades (see section 7.10.1 parts 3,4,5,6,8, and 9). To eliminate the idle time of this resource and the idle time of the trades following its activities there are three options:

A-To move the deployment points of the blocklaying crew and the trades following it forward in the network as necessary.

This solution will increase the project completion time considerably which is already unsatisfactory, and it may increase the project total cost.

B-To increase the size of the formwork crew.

This option is not economical because with larger formwork crew size, there would not be enough work space for efficient operation. Also this solution will eliminate only the idle time of the blocklaying crew which is too small to justify this option.

In addition to this the size of the blocklaying crew should be increased and the deployment points of the following trades should be moved forward in order to eliminate their idle time.

c-The third option which is adopted here is to move the deployment point of the blocklaying crew and increase its size.

The blocklaying crew in the current simulation run is deployed by node 700 at the end of the framework works in the ground floor (see figures 28-c and 16). This deployment point is changed to node 870 which marks the end of the framework works in the first floor (see figures 18 and 29-c).

The current size of the blocklaying crew is four gangs and its cost/day is £600. This size is increased by two gangs, so the cost/day becomes £900. As a result of changing the crew size the time duration of each activity has to change. The author assumed that the relationship between the level of the resource and the time duration of the activity is linear, so since the size of the crew is increased by 33% the time duration of each blocklaying activity is reduced by 33%.

Also the variable cost of each activity is changed from £600/day to £900/day. All these changes are recorded in the activity list and resource list together with the logic of the nodes 700 and 870 to be ready for input at the end of this section.

2-Plastering Crew (lab,cat-17)

In the current simulation run the plastering crew is interrupted by the first fixing activities of the finishing trades (see section 7.10.1. part 7). In its turn this resource halted the flow of the tiling crew (see section 7.10.1. part 1).

To eliminate the idle time of this resource category there is only one option which is to move its deployment point forward in the network. Currently the three groups of this resource crew are deployed at the end of the first fixing activities in the basement floor (node 1125) (see figures 19 and 34).

This is moved to node 1410 which marks the end of the first fixing activities in the first floor (figure 20). The new configuration of the flow of the plastering crew is shown on figure (35). To eliminate the idle time of the tiling crew which is caused by the plastering crew there are two options:

A-Keep the size of the plastering crew and reduce the size of the tiling crew.

This solution will increase the project completion time considerably for the following reasons:

-The deployment point of the plastering crew is moved forward and there are five plastering activities on the critical path (2075, 2138, 2146, 2160 and 2170) (see figures 34 and 64), so keeping the size of the plastering crew as it is alone will increase the completion time.

-Reducing the size of the tiling crew will increase the project completion time and will halt the flow of all finishing trades when conducting their second fixing activities.

B-The second option which is adopted here is to increase the size of the plastering crew. The size of the three groups making up the plastering crew is increased from (2,3,3) gangs (see figure 34) to (3,5,5) gangs (see figure 35).

Also the work assignment of each group is changed as well to allow an early release of the necessary workspaces for the tiling crew (see figures 34 and 35).

After changing the size of the crew the estimated time duration of each plastering activity is changed together with its variable cost. The utility data of all nodes affected by the changes are modified in the activity list to be fed later to the program.

3-Tiling Crew (lab,cat-18):

As explained in section (7.10.1.) part (1), this crew is interrupted considerably (421.97 gang days) by the plastering crew. The tiling crew in its turn prevents the flow of the finishing trades when conducting their second fixing activities (see section 7.10.1. parts 3,4,5,6,8 and 9).

The size of the plastering crew was increased (see previous section) to eliminate the idle time of the tiling crew, but this action is not enough because the idle time is too great. Another action is needed which is to move the deployment points of the groups making up the tiling crew.

In the current simulation run the tiling groups are deployed directly after the plastering work in the basement is finished (activity 1150, 1155 and 1160) (see figure 19 and 36). These deployment points are moved to the end of the plastering work in the ground floor (activity 1435, 1440 and 1445) (see figures 20 and 37) with some changes of work assignment as well.

The changes in the logic of the deployment points are recorded in the activity list to be fed later to the program. To eliminate the idle time of the finishing trades which is caused by the tiling crew there are two options:

A-To increase the size of the tiling crew to speed up the release of the workspaces necessary for the second fixing activities.
This solution is not economical or not possible because the workspace can not take more tiling tradesman for efficient operation.

B-The second option is to move the deployment points of the finishing trades when they start their second fixing activities.

This solution will be introduced when discussing the flow of each finishing trade.

The Flow Of The Finishing Trades :

As shown earlier the first fixing activities of the finishing trades are halted by the blocklaying crew (see section 7.10.1. parts 3,4,5,6,8 and 9). The size of the blocklaying was increased, but this action is not enough because the deployment point of the blocklaying crew was moved forward. So the deployment point of each finishing trade should be moved forward as well to eliminate its idle time when it starts its first fixing activities.

The same should be done to the deployment points when the finishing trade start conducting their second fixing activities (see option B of previous section).

4-Electrical Work Crew (lab,cat-11):

The deployment point of this crew when it starts its first fixing activities is moved from the end of the blocklaying activity in the basement (activity 1045) (see figures 19 and 30-a) to the end of the blocklaying activity in the ground floor (activity 1330) (see figures 20 and 31-a).

The deployment point at which this crew starts the second fixing activities is moved from the end of the tiling activities in the basement (node 1210) (see figures 19 and 30-a) to the end of the tiling activities in the ground floor (node 1495) (see figures 20 and 31-a).

5-Metal Doors And Windows Crew (lab,cat-12):

From the current resource network of this labour category (figure 30-b) one can notice that the activities of this crew are dispersed along the project with long time intervals, and the Resource Queue node (6) in this network recorded all the idle time of this crew (see section 7.10.1 part 3).

In order to eliminate the idle time without causing any idle time for the following trades or the trades working in parallel with this crew , it is logical to separate the activities of this labour category and increase the number of its return visits. This solution results in a new resource network which is shown on figure (31-b). The size of the crew in this new flow is fixed to two gangs. This new network required an additional two SINK nodes and two Resource Queue nodes.

These extra nodes are added to the resource list to be fed to the program. The logic of the activities affected by this action together with their estimated time duration and variable cost are changed and recorded in the activity list.

6-Wooden Doors Crew (lab,cat-13):

As section (7.10.1. part 5) showed the majority of the idle time of this resource is caused by the tiling crew and recorded at the Queue node (12 and 14) (see figure 30-c).

The deployment point at which this resource starts its first fixing activities is kept unchanged (see figures 30-c and 31-c). The deployment point at which this resource starts its second fixing activities is moved from the end of the tiling activities in the basement floor (node 1210) (see figures 19 and 30-c) to the end of the tiling activities in the ground floor (node 1495) (see figures 20 and 31-c).

7-Aluminum Windows And Doors Crew (lab,cat-14):

Its deployment points are moved from the end of the blocklaying and tiling works in the ground floor (nodes 1330 and 1495) (see figures 20 and 32-a) to the end of the blocklaying and tiling works in the first floor (node 1615 and 1780) (see figures 21 and 33-a).

8-Central Heating Crew (lab,cat-16):

As section (7.10.1. part 6) showed that the majority of the idle time of this crew is caused by the tiling crew. To eliminate this part of the idle time, the flow of this crew is split into two parts: first fixing and second fixing activities which requires a second site visit.

In order to eliminate the idle time at the first fixing work, the deployment point at the end of the blocklaying activity in the basement floor(node 1045) (see figures 19 and 32-c) is moved to the end of the blocklaying works in the ground floor (node 1330) (see figures 20 and 33-c). Also to eliminate the need for extra Resource Queue nodes in the network, the Queue node (2) (figure 32-c) is changed to multi-successor Queue node (figure 33-c), and the Queue node (6) is changed to a SINK node. The crew visits the site again when the tiling work in the ground floor is finished (node 1495) (see figure 20 and 33-c).

9-Plumbing Crew (lab,cat-15):

Its deployment points are moved into the same location of those of the aluminum doors and windows crew (part 7 of this section) (see figures 20, 32-b, 21 and 33-b).

10-Painting Crew (lab,cat-20):

As section (7.10.1. part 2) showed, the flow of this resource is halted by the second fixing activities of the finishing trades. Since all the painting activities are not critical moving the deployment point of this crew will eliminate the idle time without affecting the project completion time.

The deployment point is moved from the end of the second fixing activities in the basement (node 1290) (see figure 19 and 38-b) to the end of the second fixing activities in the ground floor (node 1575) (see figures 20 and 39-b).

7.11. Simulation And Analysis (second run):

After changing the utility data of all the nodes affected by the resource balancing actions, the simulation is run again for 100 iteration. The results of this second run are summarized in figures 71 to 82. Figure (71) shows a summary report on the project milestones and terminal node. The information shown on this figure together with the statistics of the realization time are arranged in a table shown on figure (41). On this figure, for example, the milestone (1320) which marks the end of the works in the basement floor has a time target equal to 218 days and a cost target equal to £ 313,000.00.

In the first simulation run its realization time was between day 223.47 and day 240.44 which means that the probability of achieving its time target is zero. In the second simulation run (after balancing resources) its realization time is between 208.70 and 221.94, and on average it is realized at day 215.13. So the probability of achieving its target date has improved from zero in the first run to 0.89 in the second run (figure 41).

Figure (72) displays a print-out of the probability distributions of the project completion time in the second run. It shows that the project can be completed between 233.65 and 247.81 days, and on average within 240.09 days. Compared with the first run the average completion time is reduced by almost 25 days because of balancing the resources. The probability of achieving the time target is improved from zero in the first run to 0.97.

Figure (73) displays the statistics of the project net cost for the second run. It shows that the average net cost is reduced from £2,426,184.50 in the first run (figure 45) to $2,368,716.00 in the second run (figure 73). This is due to the reduction in the completion time which reduces the total cost of site overheads and the total cost of operating the crane and the hoist.

Figure (74) shows the distribution of the idle time cost of all resources. Compared with the idle time cost in the first run (figure 46), this cost is reduced from an average of £275,560.31 to an average of £ 39,446.54 in the second run (figure 74). This means that the idle time cost is cut by 86% as a result of the first attempt at balancing the involved resources.

Figure (75) displays the distribution of the project total cost for the second run. It showed that this cost is improved from £2,701,745.00 on average (figure 47) to £2,408,182.80 as the result of reducing the project completion time and balancing resources. The probability of achieving the project target cost is improved from zero (figure 47) to unity in the second run (figure 75).

Figure (76) displays a print-out of a list of the project activities in the order of their criticality index. Obviously some of the activities which were critical in the first run became non-critical in the second run and vice versa.

Figure (77) shows a summary report on the involved labour resources for the second run. There are three categories still experiencing interruption. The idle time of these categories can be eliminated by following the same procedures which are explained in section (7.10).

Figure (78) displays a summary report on the machinery resources for the second run. As it is shown they do not have any idle time.

7.12. Resource Schedule:

After finishing the last simulation run which produces a satisfactory completion time and acceptable level of idle time perhaps zero, the program can produce detailed reports and schedules for all project activities and all the resources involved.

Figure (79) shows a print-out of a detailed report on the site excavation crew. Since this resource did not record any idle time during the simulation its resource Queue nodes recorded zero. The SINK node (8) (see figure 24-a) in this report recorded an average realization time equal to 18.30. This means that the site excavation crew will be expected to leave the site between day number 17 and day 20 but most likely at day 18 (see first part of figure 80).

Figure (80) shows a schedule for the activities of this excavation crew. It displays a statistic on the starting time of each activity and its estimated duration also a statistic on the time at which the excavation crew can leave the site.

7.13. Activity And Space Queue Node Schedule:

Figure (81) shows a print-out of a schedule for all the activities and milestones of the sub-networks A and B (see figure 13 and 14). Figure (82) shows detailed information on the Space Queue nodes and the Function nodes of the Sub-networks A and B.

For example site surveying and layout work (activity 10) (see figure 13). It is preceded by one Space Queue node (4) and succeeded by two Space Queue nodes (20 and 25). This information is shown in the second and third columns in figure (81) as S-4 which means that the activity is preceded by Space Queue node (4) and succeeded by S-20 and S-25. Also this activity is carried out by the surveying crew which is coded as labour category number (1).

Figure (26-a) shows the flow of this resource, and activity (10) is preceded by one Resource Queue node (2,L-1) and succeeded by one Resource Queue node (4,L-1) and the size of the crew is one gang. This information is shown in the fourth and fifth columns in figure (81). As shown on this figure, activity (10) has fixed cost equal to £100 and a variable cost of £250/day, which is the cost of the surveying crew. Also the second run reveals that this activity can start at day number one and is on the critical path, because its criticality index equals unity (at the top of the information of activity 10 in figure 81). Its estimated duration is constant and equals one day.

Figure (82) shows that the Space Queue nodes (20 and 25) which follow activity (10) recorded zero waiting time which means that the free float of activity (10) equals zero. Also figure (82) shows the total cost of site overheads during site set-up which is recorded by BETWEEN node (8) (see figure 13). On this figure the cost ranges between £3,354.95 and £4,035.47, but on average it is £3,707.53. All the information regarding the overhead cost and the operating cost are listed in the table of figure (42).

Chapter Eight

Conclusions

8.1. Introduction :

This work introduced an extensive review of the available planning techniques and their deficiences. Throughout the discussions in chapters two and three, and the case study introduced in chapter seven, it was shown that C.P.M is good enough for planning at the summary level, but it is fundamentally a poor model of the production process at the construction phase.

The C.p.M model suited the upper level of management in organizing time committed to the project and the establishment of goals. But for the site management, these goals actually act as a requirement that must be met by deploying resources. The main problem on site is the dynamic commitment of resources and their maximum utilization. In the absence of a technique for analyzing the interactions of field resources and activities, field management has been and is still relying on an ad-hoc reference system based on experience, common sense, intuition, and instinct.

Attempts have been made to develop more realistic models which can satisfy the requirement of detailed planning and control at the site level. The technique produced in this thesis relied on the idea of modelling the production process as a queuing system and on the heuristic concepts and rules which are used by field management.

The concept of the model is an attempt to satisfy the needs of site management by including the availability and flow of resources, and to preserve a proper link with the upper levels of management by including milestones.

No matter how good the model is, it is useless if not used, therefore, a special care was taken throughout the development of the model to produce a methodology with a minimum interruption of the traditional method of working of the construction industry. Also, every effort has been made to eliminate the major practical problems associated with the original network model.

The technique with the developed software allows a complex project with numerous activities and a large number of resources to be easily modelled by the planner or by site management. It models project activities, work locations, the availability and flow of each resource together with their interactions, direct costs whether they are function of time or not, and indirect costs of all sorts.

It is well known that there is an inverse relationship between complexity and usability. This is demonstrated by the fact that the bar chart is still by far the most widely used method for presenting a project's plan and schedule. For this reason the structure of the model is kept as simple as possible but to a degree which does not affect its intended function and modelling capability. Also, an effort has been made to make the model and its software flexible enough to accommodate a gradual adoption of the technique and its methodology in practice.

While the drawing of the main network and the resource flow networks is cumbersome, the concept and the function of the modelling elements of the technique are clear and easy to understand. The input to the software is simple and can be done by any of the management staff on site. The output is self-explanatory, easy to read, interpret and use.

The model and its software have many features and capabilities that make them attractive, but as in the case of any new developed network technique, no firm conclusions on its applicability and deficiences can be drawn until it has been used to model a number of different types of project in practice. Nevertheless, from the case study and the description of the structure of the software, it is possible to draw three set of conclusions :

- Conclusions on the model structure and its capability.
- Conclusions on the software and its analysis.
- Conclusions on the limitations of the model.

The first two sets of conclusions highlight the contribution of this work, and show that the objectives of this research which were outlined in chapter three (section 3.4) have been achieved.

8.2. Conclusions On The Model Structure And Its Capability:

They can be summarized as follows:

1-The design of the main network to represent the absolute logic controlling the sequence of project activities, and resource networks to represent the preferential logic and the flow of resources has the following important advantages :

- It makes the process of planning far easier than in any other technique. The planner can model the technological logic between project activities precisely and in a clear way. He releases his mind from thinking about the possible sequencing logic. Then by using the resource network he can experiment with different policies of achieving the work. It helps him to make the decisions on the logic, resourcing and time in a serial way.
- The logic in the main network stays valid throughout the scheduling and execution phase without the need for any change. The main network of the case study (see figures 13 to 23 in the appendix) did not change throughout the scheduling stage. Only some of the resource network changes throughout the scheduling process. The changes are usually minor and mainly concentrated on the deployment points of resources.

In the case study the seven networks representing machinery resources (see figures 24 and 25 in the appendix) did not change. While ten out of twenty one labour resource networks (see figures 26 to 39 in the appendix) have only minor changes. While in the C.P.M technique, the whole network has to be restructured .

2-The adoption of the COMBINATION node to represent activities which consume physical resources makes it possible to model the flow of more than one resources through each activity.

The added features of this node such as the capability of modelling the costs of material, both those that are a function of time and those unrelated to activity duration. Also its ability to represent activity time duration as a constant value or as a random variable represented by different distributions, makes this node a very powerful modelling element. It enables the planner to model all the variables (time and cost) and study them all at the same time to make trade-offs between different methods of working, sequencing and several deployment policies.

3-The most important contribution of this work is the introduction of the concept and function of the Space Queue node. This node represents the most important modelling element in the proposed technique and its analysis. It plays the following powerful roles:

-It represents the idle state of the work location pending the availability of the required resources and the satisfaction of the technological logic of the immediately succeeding activity. With the information this node records, the planner can spot the bottlenecks in the plan and can alter the preferential logic, the deployment point of specific resource or the composition of some critical resource to meet the target.

-The idle time this node records represents the available free float on the immediately preceding activity. This eliminates the confusion of having several types of float. So that the planner at the scheduling stage can rely on this float to experiment with different policies of resourcing. The controller at the site level can use this float without worrying about the following activities.

-The most interesting point is that the float recorded by this node is caused not only by the dependencies between activities but also by the interaction between resources. As a result , in the network even critical activities may have float.

For example: the building layout activity (figure 13 in the appendix) is critical, the Space Queue node (45) recorded an average free float of 6.132 days (figure 82 in the appendix). The S.Q.node (50) recorded the same. This means that if the surveying crew is delayed by this amount of time, the start of the immediately following activity (activity 165 "reduce level" and node 60 figure 13) will not be affected at all.

-The Space Queue node with the cost function carries and directs the flow of the accumulated cost through the network.

This is a very powerful facility and very easy to use. It helps the planner to direct the total cost to a specific point in the network. He can therefore isolate each stage of the project for separate control at the execution phase.

4-The design of the BETWEEN node and its intrinsic function makes it possible to model the cost of the resources which have to be shared by several activities or trades.

This element enables the planner:

-To model the site overhead cost, not only for the project as a whole but for each stage, if the daily overhead cost changes from one stage to another. This allows the evaluation of the schedule in terms of the total cost. The planner can observe the effects of the overhead cost on the total cost of the project.

The average total cost of site overhead during the site set-up part of the project (node BT-8, figure 13 in the appendix) changed from £3,651.53 in the first simulation run to £3,707.53 in the second run (see figure 42).

The average total cost of site overhead of the rest of the project (node BT-160, figure 13) changed from £246,073.98 to £220,553.06, a reduction of nearly 10% (£25,520.92) (see figure 42).

-To model the operating cost of some machinery or equipment which has to be shared by several trades and where it is difficult to assign this cost precisely to the relevant works and activities.

The average total operating cost of the tower crane (BT-140, figure 13) was reduced from £66,107.27 to £53,727.00 in the second run (see figure 42).

5-The adoption of both types of Resource Queue node from CYCLONE with the extra features added to them (i.e. the consideration of the cost of resources) contributed to the versatality of the model. They provide an important notation for modelling the idle state and the availability of resources.

None of the available techniques has the facility to model the availability of resources, the cost of their idle time and their effects on the total cost of the project.

These modelling elements enable the planner:

-To define the critical resources which halt the progress of other resources. He can increase the level of the critical resource or decrease the amount of resources which recorded idle time or he can change the deployment points to balance all resources at the same time.

For example : the tiling crew recorded an idle time of 6.76, 45.13, 35.52, 29.43, 121.25 and 39.65 gang days at the Resource Queue nodes 8, 12, 18, 14, 10, 16 respectively (see figures 36 and 51 in the appendix). These idle times are caused by the plastering crew which occupied the workspaces necessary for tiling activities.

-To balance the resources in a very efficient way. This depends on the experience of the planner and the reliability of the necessary data.

For example: all the machinery resources are balanced at the first run. All of them recorded zero idle time (see figure 50, appendix). Ten out of twenty one labour resources recorded idle time at the first run (see figure 49).

The first attempt at balancing labour resources reduced to zero the idle time of seven out of ten categories (see figure 77).

The tiling crew at the first run recorded an average total idle time of 421.97 gang days with average total idle time cost £63,295.48 (see figure 51). At the end of first attempt at balancing the resources, this idle time is reduced from £421.97 gang days to 50.39 gang days with a total idle time cost of £7,558.515 (see figure 77). This is a reduction of almost 88%. So the technique using these modelling elements is very efficient in balancing resources.

-To change the size of the resource crew at any stage of the work.

For example: the plumbing crew at the start has one gang, after finishing the plumbing works for the temporary service, the size of this crew is increased to three gangs (see figure 26-d, appendix).

-To move part of a specific resource crew to another.

For example: If a J.C.B is used at the start of the work by the excavation crew, then after the excavation work is finished, it can be moved to form part of the backfilling crew. It is possible, using these modelling elements, to move the J.C.B from the excavation crew to do some earthmoving works with the earthmoving crew then come back to join the excavation crew again. This flexibility overcomes all the deficiences of the resource allocation and resource levelling algorithms.

Another very important feature of the Resource Queue nodes is that they are valuable elements in modelling the flow of resources in multi-project situations.

If there are several projects to be run at the same time, each project can be considered as a sub-network which can be linked with others to form one complete network for the whole projects.

By using Resource Queue nodes, it is possible to study different policies for deploying and moving resources between these projects. It is a very valuable facility especially for considering the movement of heavy and expensive resources such as excavation equipment, tower crane ...etc.

6-The design of the SINK node provides the facility to define in the schedule when each type of resource is likely to finish its activities and to be released from the site.

This information is important for the central planning office, recruitment office, and for the higher levels of management as well.

It helps in making the decision to bid or not to bid for new jobs. In the case study, the schedule of the painting resource shows that four gangs are expected to be released at day number 239 at the SINK node (10), and another two gangs are expected to finish their activities at day number 246 at the SINK node (14) (see figures 38-b, and 54 in the appendix).

7-The introduction of the ACCUMULATOR node enables the isolation of any part of the project to be studied separately in terms of cost. The planner can concentrate on the trouble spot in the project and try to change whatever is possible in this part to achieve the predefined target cost. At the control stage, it is possible to spot the cause of cost overrun and take appropriate corrective action.

8-The definition of the concept of the FILTER-1,2,3 output logic together with their registers, gives the model more strength in terms of scheduling and control.

-It helps the planner to link the detailed plan with the summary plan through common milestones. The time and cost constraints imposed on these milestones in the summary plan can be imposed on the same milestones using these logics in the detailed plan.

At the scheduling phase the planner can study the effect of different sequencing and resource deployment policies on the achievement of the time and cost targets imposed on these milestones.

In the case study the milestone node (530)(AND-FILTER-3) which represents the end of the substructure work is common to the milestone (35) (see figure 11) in the summary network. The time target of this milestone is 99 days and the target cost is £476,000.00 (see figures 40 and 41).

At the first simulation run, the probability of achieving the time target was 0.52, while in the second run it is improved to unity (see figure 41). The cost target can be achieved with certainty in both runs.

This is a very important facility, because it can alert higher levels of management to change the targets in their summary plan if these targets can not be achieved. Also, at the control stage if any changes happen which affect the achievement of the targets at each stage, the information provided by the FILTER logic helps the management to alter policy or take different courses of action for future stages.

9-TERMINAL-1,2,3 logics with their registers represent a major contribution of this work.

They generate important information for evaluating the output schedule as a whole in terms not only of time as in C.P.M or in terms of time and net cost as in C.P.M/Cost or the time-cost trade-off, but in terms of the total cost including the overhead cost and the cost of the idle time of all the resources involved.

It helps to study the effects of different resourcing policies on the total time and cost of the project. At the scheduling stage this information directs the planner to change the sequencing, the deployment points of resources, the make up of some crews until he obtains a solution with zero or minimum idle time.

In the case study the output schedule of the first simulation run results in an idle time of resources with average total idle time cost of £275,560.3 (figure

46). The second run following the first attempt at balancing resources reduces this cost to £39,466.5 (figure 74), a reduction of almost 86%.

The effects of the idle time and its cost together with other costs such as the overhead cost and the operational cost of some machinery on the net and total costs of the project is very considerable.

At the first run the net and total cost were £2,426,184.4 and £2,701,745.0 (figures 45 and 47) respectively. At the second run these costs are reduced to £2,368,716 and £2,408,182.8 (figures 73 and 75).

The probability of achieving the time target which is 245 days improved from zero in the first run to 0.97 in the second run (figure 41).

10-The most important feature of the technique is that the schedule of activities and resources are obtained in a single step while in C.P.M scheduling is done through three stages: running the network analysis, using the resource allocation algorithm, finally running the resource levelling routine.

11-The technique solved the problem of C.P.M/Simulation output by producing only a range of starting times for each activity schedule and its estimated duration.

Figure (81) shows the schedule for setting up the site accommodation (85) (see figure 13). This activity can start between days 9 and 11, but is most likely to start at day 10. Its estimated duration is uniformly distributed with a minimum value of 6 days and a maximum value of 8 days.

This schedule means that this activity can start at day 11 and takes 8 days to finish without affecting the total time of the project. This is because the variability of its duration was taken into account during simulation.

This eliminates the confusion of producing a range for early and late start and finish for each activity as is the case with C.P.M/simulation.

The scheduling information produced by the technique can be presented by bar chart to be used by foremen and other lower levels of management.

12-The technique preserves the most important feature of network analysis, management by exception. It defines the criticality index of each activity.
At the planning and scheduling stage, this information directs the planner towards the areas which have potential for improving the schedule.
During the process of balancing resources, the planner pays special attention to the resource which has the maximum number of critical activities. At the control stage, efforts will be directed towards the activities with least float and most criticality.
Figure (48) shows a list of the case study activities in the descending order of their criticality index.

13-The flexibility of the model enables a general adoption of its methodology. One of the major difficulties in practice is to obtain probabilistic estimates for the time duration of each activity and to produce estimates for all types of cost required by the technique.
The facility for representing the time duration of each activity as a constant value allows the planner to use the technique as an alternative to C.P.M. In this case the user can ignore the cost parameter, and with one iteration will obtain a schedule for the project activities and resources together with the idle time for each resource.
The use of the technique in this case is far better than using C.P.M, as it generates information which C.P.M is unable to produce.

In summary, the model provides the format to the user for repetitive sequencing of the decision cycle associated with the selection of levels of resourcing and deployment before actual work commitments are made.

This capability enables the planner to check the impact of a variety of decisions and policies and provides a framework for evaluating alternative sequencing, resource allocation and deployment in terms of total completion time and cost of the project as a whole. The planner can use the level of detail suitable for the construction phase and which can meet the need of site management.

Since the technique mirrors the way field management thinks when controlling field activities, site management can participate in the planning and decision processes associated with the construction phase. This feature of the model allows the higher levels of management to consider work sequencing and the details of the construction phase through the eyes of field management.

The capability of the technique for generating information on idle time and the effect of each factor on total cost makes the consequences of any chosen policy clear to everybody involved, which in turn boosts their confidence in the plan and the output schedule.

8.3. Conclusions On The Software And Its Analysis:

The package is designed to be user friendly. With little training, any member of site management can use it even in the absence of a manual. The capability of the software and its feature can be summarized as follows:

1-The division of the software into three modules : input, simulation, and output and their interlinked menus makes the package very easy in terms of accessing its facilities.

The large number of prompts available in each routine, and the messages which force the user to check the input reduces the possibility of inputting wrong data.

Once the data regarding the main and resource networks are input to the package, they can be stored and copied to different files. This allows the user to keep the results of a number of trials. If he finds later that the previous solution is better than the current one, he can produce the output schedule of that solution without the need to remember the changes and re-run the simulation and its analysis again.

This facility is valuable at the control stage of the project where several updated versions of the schedule can be stored and be referred to later.

2-The structure of the files used to store the input data and output schedule are designed in a way that allows the package to be linked easily to any costing or estimating package. This facilitates the computerization of estimating the time duration and cost of each activity, and building productivity data base for the contractor organization.

3-The package is written on a machine using MS.DOS 2.11 version as an operating system. It is therefore easy to transfer this package to any machine using any upgraded version of MS.DOS.

4-The simulation module is designed to use the external storage facility of the machine for storing and retrieving the necessary data for simulation. This eliminates any restriction on the size of the network which this package can handle.

But this method of handling the data unfortunately reduces the speed of the analysis.

The computation time of each iteration depends on several factors such as: the complexity of the network, the number of resource networks, the size of each network, the number of Resource Queue nodes ...etc.

The network of the case study introduced in chapter seven has almost 700 nodes. Each iteration of the simulation run took almost three minutes to be achieved.

The simulation was performed on a machine with a processor running on 4.6MH. Nowadays there are personal computer in the market with processors running on 25 Mh. This means that the iteration of the same network will take 33 seconds on the modern machine. If the simulation run is conducted using a RAM disk instead of the external storage, the computation time (33 seconds) can be reduced by two thirds to 11 seconds.

5-The most important feature of the package is its capacity to produce the output information in several forms.

- -It can produce a schedule only for the milestone and the terminal nodes of the project (figure 43). This shows the realization time of each stage of the project and for the project as a whole. This suits the purpose of the upper levels of management.
- -It produces a schedule for the activities of each type of resource (figure 52) as required by the foreman for each.
- -Also it can produce a schedule for the activities of each stage of the project and for the project as a whole, the level desired by the site manager. This flexibility of output is valuable, because it can suit any form of site organization.

8.4. Limitations And Deficiences Of The Model :

Despite the advantages of the model, there are some deficiences which can be summarized as follows:

1-The division of the presentation of the model network into the main network and resource flow networks results in drawing almost every activity and the milestone nodes at least twice, once in the main network and perhaps once or more in the resource networks. This duplication in drawing the networks is unavoidable as it is necessary to make the network readable and manageable.

The burden of drawing and this deficiency can be eliminated by computerizing the process of drawing the network. This is possible with the advanced graphics facilities now available.

2-The inclusion of the cost parameter in the model will result in the same cost accounting problem as in C.P.M/PERT-Cost. The company has either to abandon its cost-accounting system and rely on the technique or it has to live with two costing systems.

This problem does need separate research to find a more appropriate costing model which can satisfy both the need for operational costing based on activities and the need for cost accounting based on departments and divisions.

3-The model considers the availability of resources in terms of quantity only, not in terms of when. In other words, the resources in the model are deployed at a specific points in the network. The output of the analysis (i.e. the schedule) defines when these deployment points are likely to occur.

If the resources required can be made available by their release from other on-going projects, the problem in this case is solved by conducting multi-project planning.

In many cases the resources are estimated to be available at a specific point in time. The model with its current structure is not able to handle this situation.

4-The technique considers only the variability in the time duration of an activity. It is unable to model the effects of uncertainty caused by interference factors such as : weather, delay of materials, labour absenteesm..etc.

With its current structure, it is possible to model only the effects of the late arrival of material by using the NORMAL node to represents a probabilistic time delay. But the model has not yet the ability to model the effects of other factors.

Chapter Nine

Recommendation For Future Work

Several areas of research can be suggested for future work:

1-One area of research is to enhance the modelling capability of the technique.

It is possible to design the following modelling elements :

A-INITIATOR:

A node which can initiate the flow of any resource through the network at a specific point in time defined by the user.

This will be used for resource deployment instead of using the nodes in the main network. With this node, it will be possible to model the availability of resources in terms of quantity and in terms of when as well.

B-STOP WATCH :

This node can be timed by the user to halt the progress of simulation at different time intervals within the project duration.

The function of this modelling element is to calculate the cost and value of the work achieved during each interval. This helps in producing a cash flow envelop for each stage of the project and for the project as a whole.

C-Weather WATCH :

This node can generate the weather conditions at each calendar date. A special flag can be incorporated in the structure of the COMBINATION node which will show whether the activity this node represents is vulnerable or not to a specific set of weather conditions.

Throughout the simulation, each day all activities in progress will be scanned, and each activity affected by the weather conditions an extra day or less will be added to its sampled duration. In this way the effects of weather on the work progress will be taken into account in parallel with other factors.

D-Extra features can be added to the TERMINAL-1,2,3 logics.

These might include the capacity to handle penalty and bonus clauses for late or early completion of the project. In this case total cost will represent reality more accurately. These new features require changes in the simulation algorithm and consequently in the software.

With the advances made everyday in computer technology, it is possible to change the simulation routine from scanning the time at the end of each event to a fixed interval (e.g. everyday). Also, it is better in terms of speed to rely on the RAM as a storage for Input output of the simulation process.

2-Another major area for research would be to include a decision support system based on the methodology of the technique. Two parts can be defined in this area:

A-Since the main network is based on the absolute logic, it is possible to build a knowledge base library. This library contains a sequencing logic between the activities classified in terms of type of project.

So by building an interactive software package, it is possible to generate a network plan for any type of project.

The most difficult task is to computerize the generation of the resource network, but it is possible to design an inference engine linked to the knowledge base to generate such types of network.

B-The second part is to computerize the process of resource allocation and balancing.

This will need much effort in the design of a set of algorithms which can scan the network backward and forward to identify the possibility of changing the deployment points, the size of each crew, the preferential logic ...etc, in order to define the best possible strategy.

This needs knowledge base as well, for choosing the best route along the resource balancing process.

3-A possible area of work would be to modify the structure of the model to handle several levels of detail and to link :

-these different levels together.

-the model with C.P.M technique.

-the model with both costing and estimating package.

This idea can lead to the design of an integrated project management system. The work involved in this area of research can be outlined as follows:

A-Design or adopt a data base system which can store the quantity and the type of resources required for each type of work compatible with the form of Project Breakdown Structure chart.

B-Computerize the process of quantity taking-off from the detailed drawings using a digitiser.

C-Develop a package which can generate the drawing of C.P.M network, and which can be linked to the modified version of the technique.

D-Computerize the drawing of both the main network and resource networks designed by the user.

E-Link the input module of the technique to the data base package.

With this system the burden of drawing all the networks and the input process will be eliminated. The effort of the user will be released to concentrate on the decision making process, for resource allocation and balancing to produce the final plan and schedule.

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Appendix

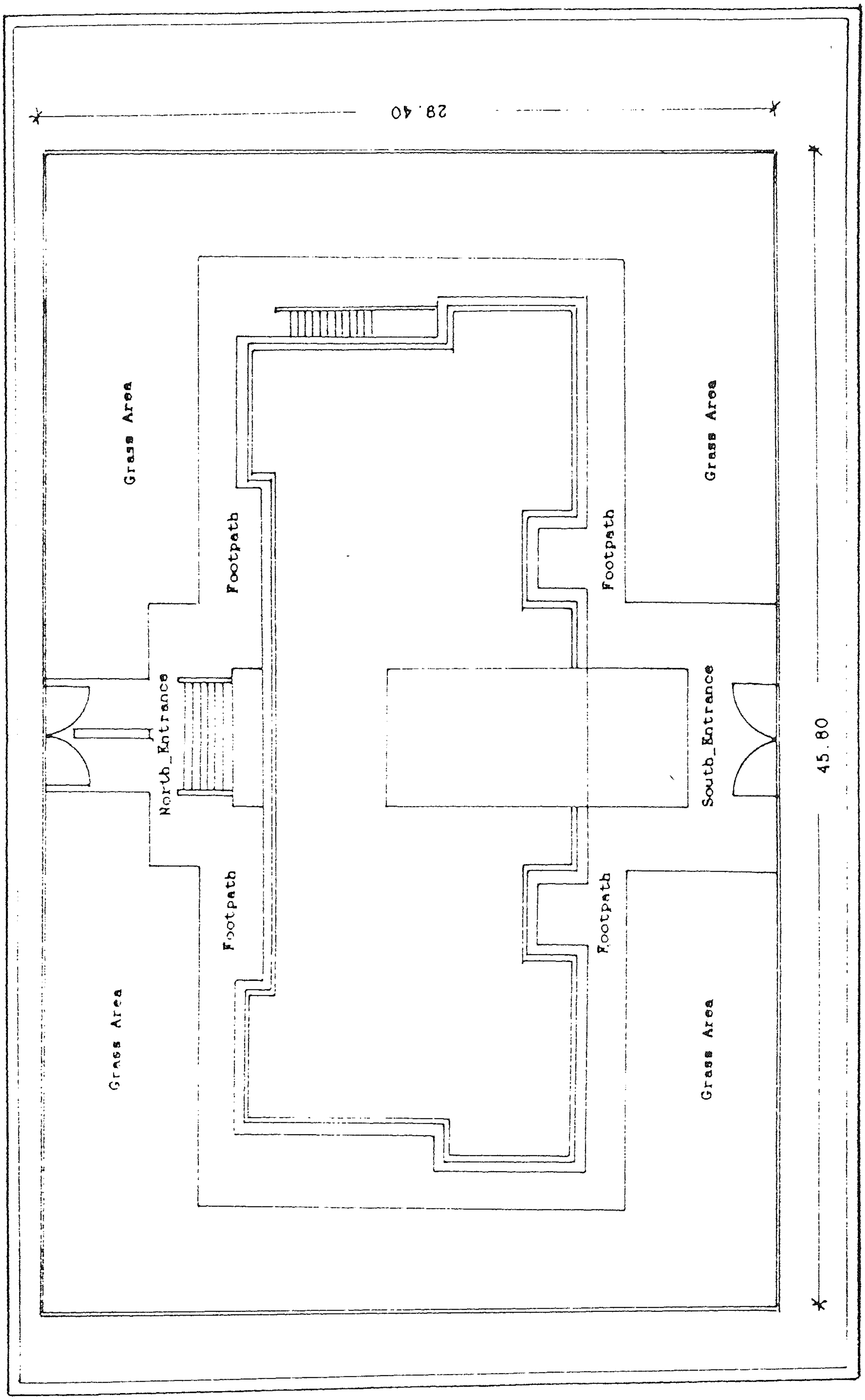

Figure (1)- General Plan.

Figure (2)- South And North Elevation.

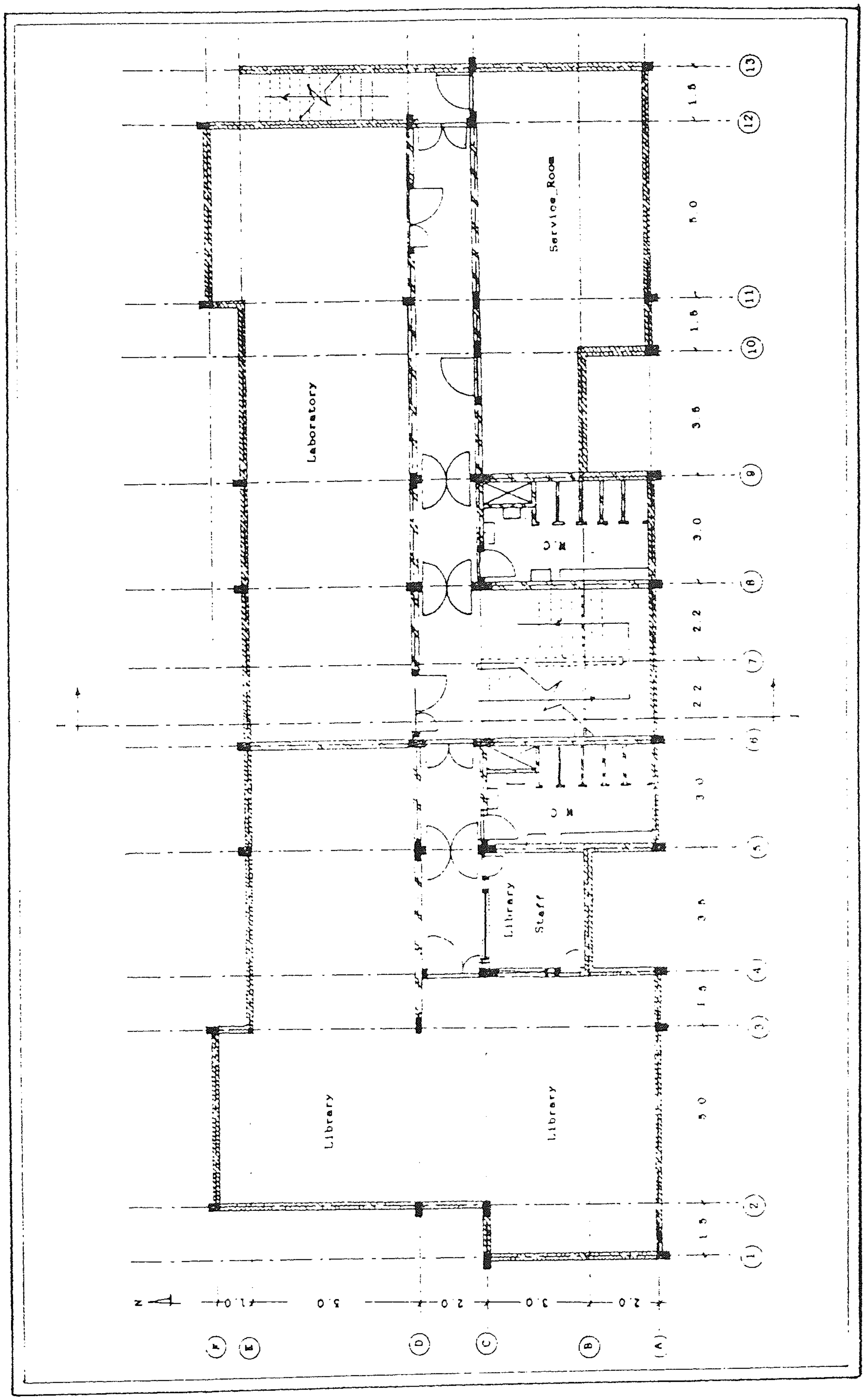

Figure (3)- Basement Floor Plan.

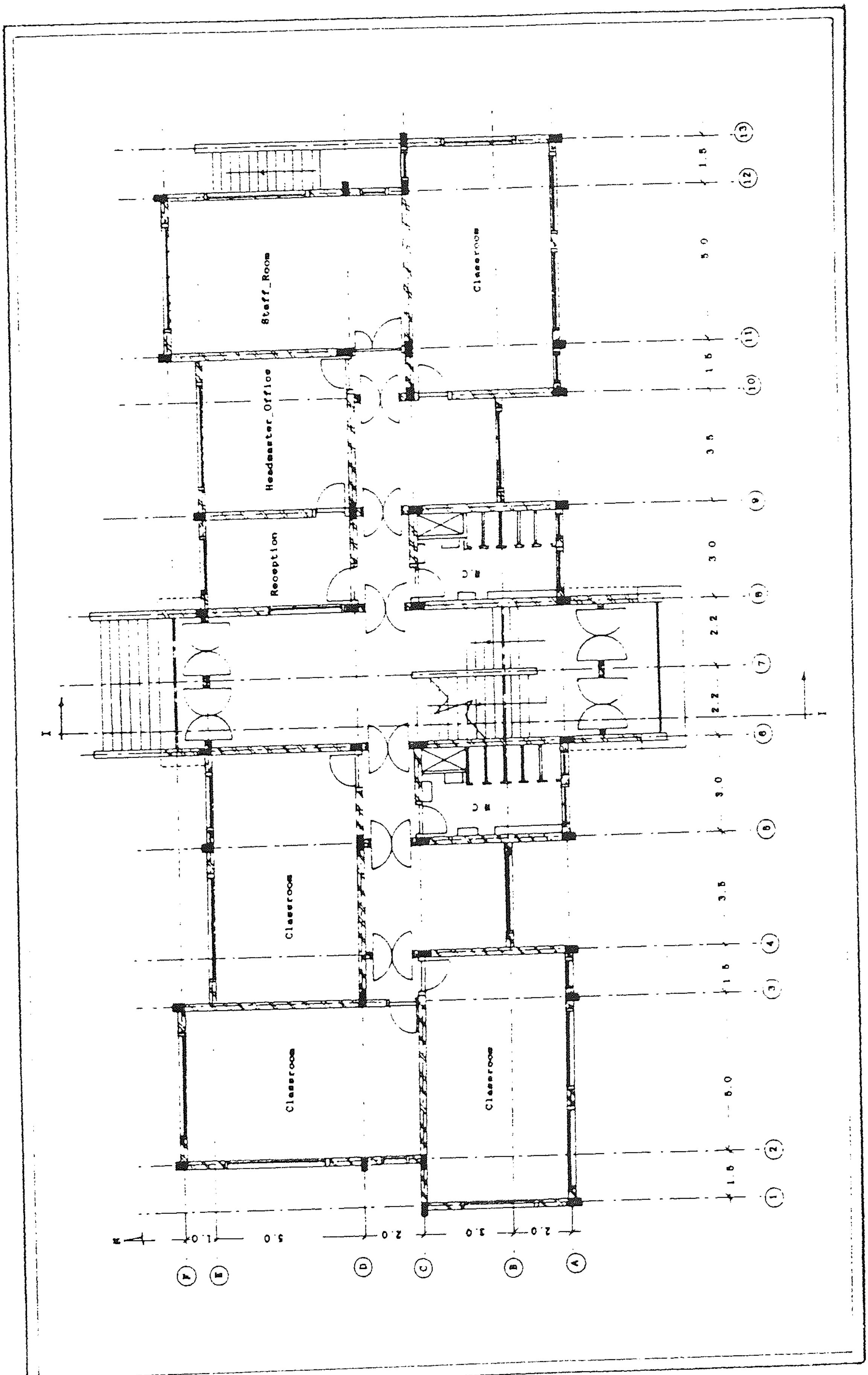

Figure (4)- Ground Floor PLan.

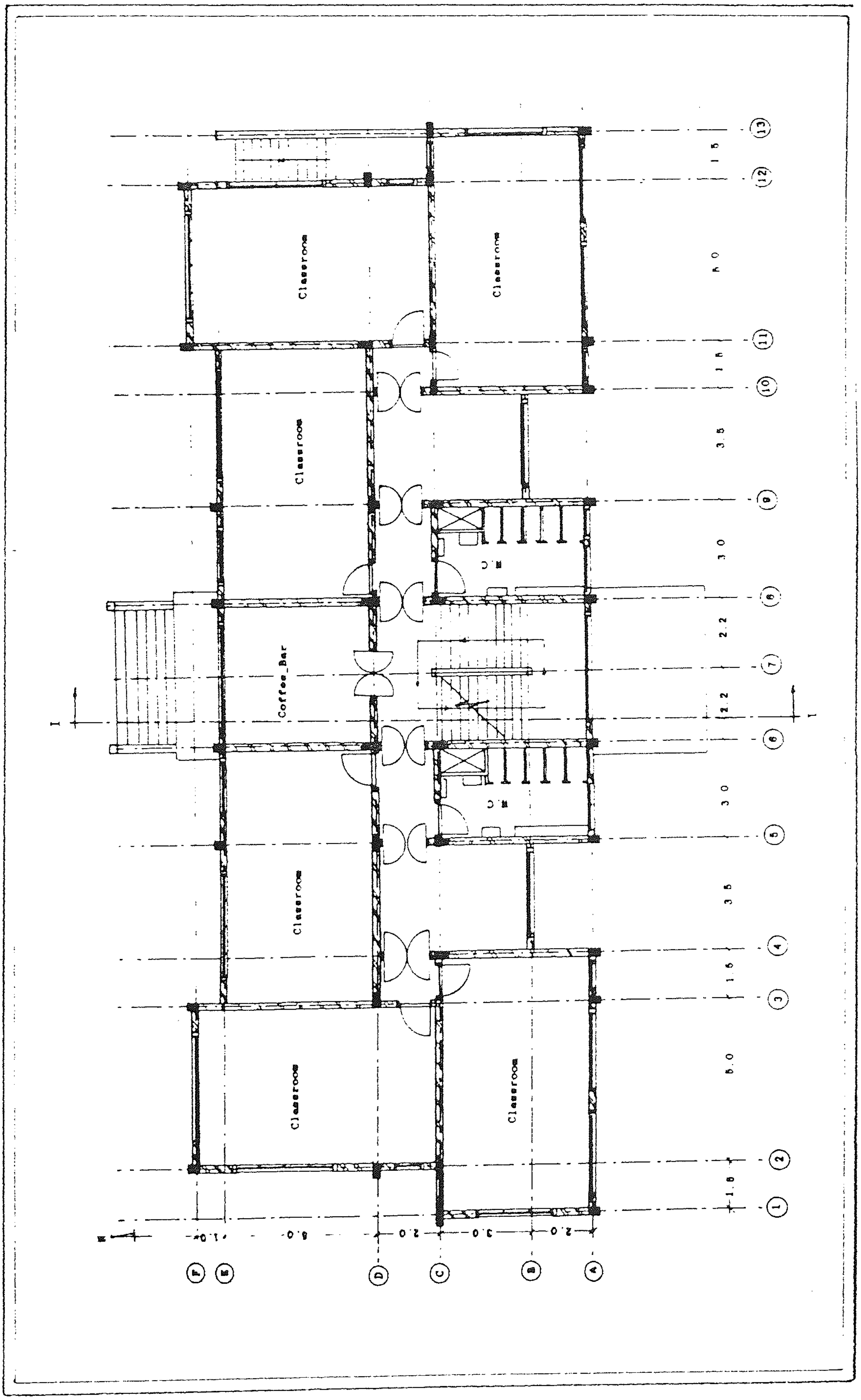

Figure (5)- First Floor Plan.

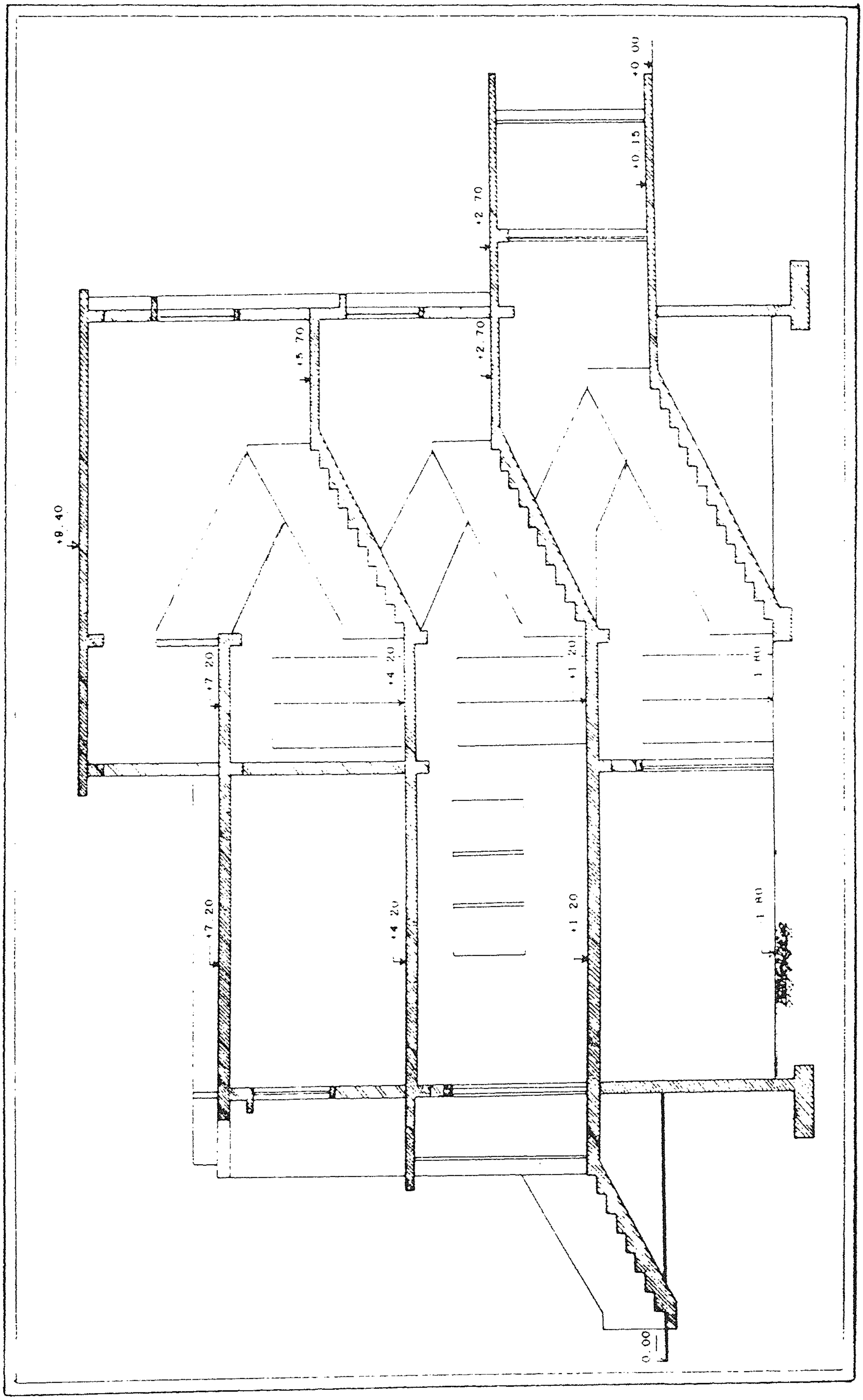

Figure (6)- Cross Section I-I.

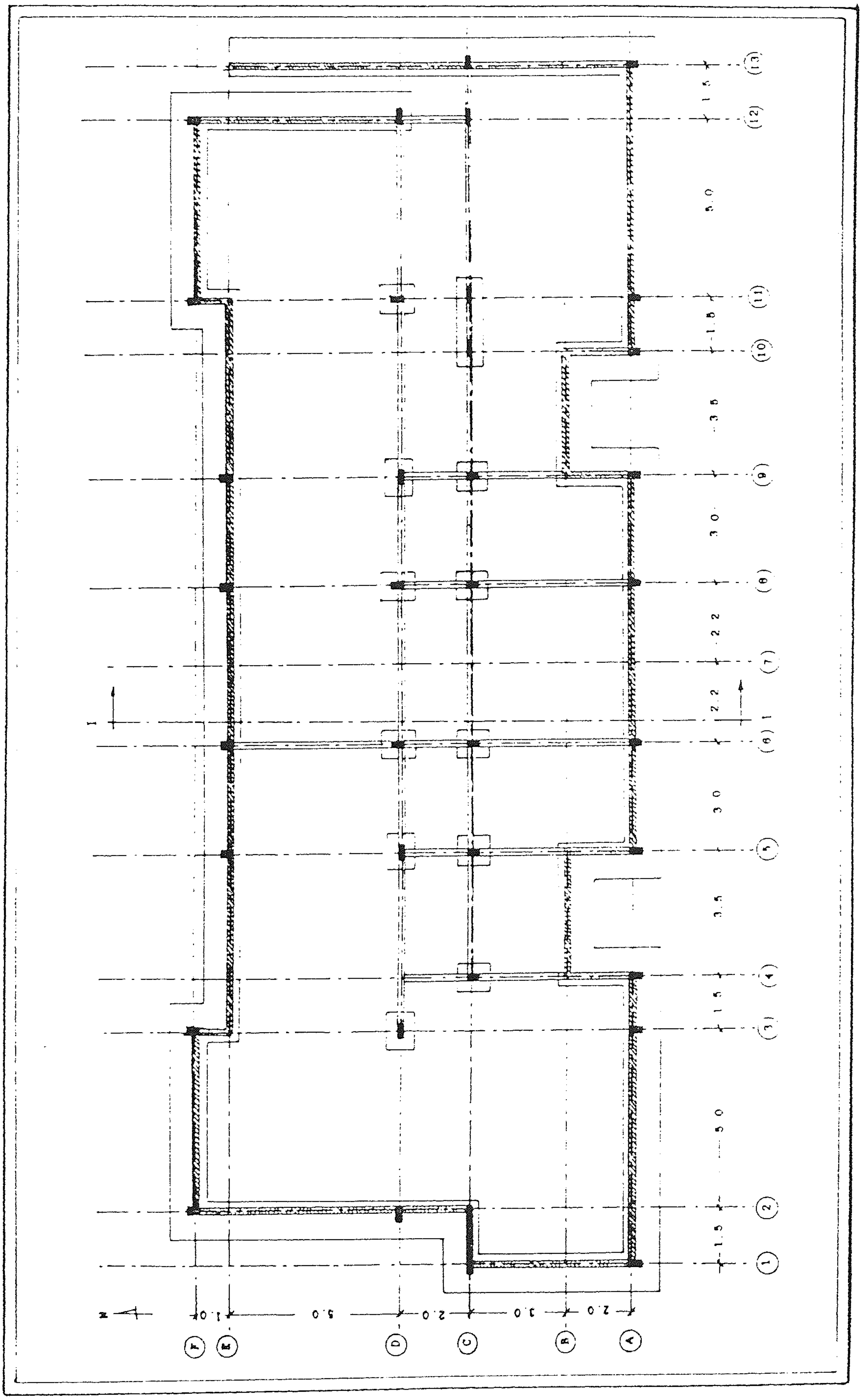

Figure (7)- Foundation Plan.

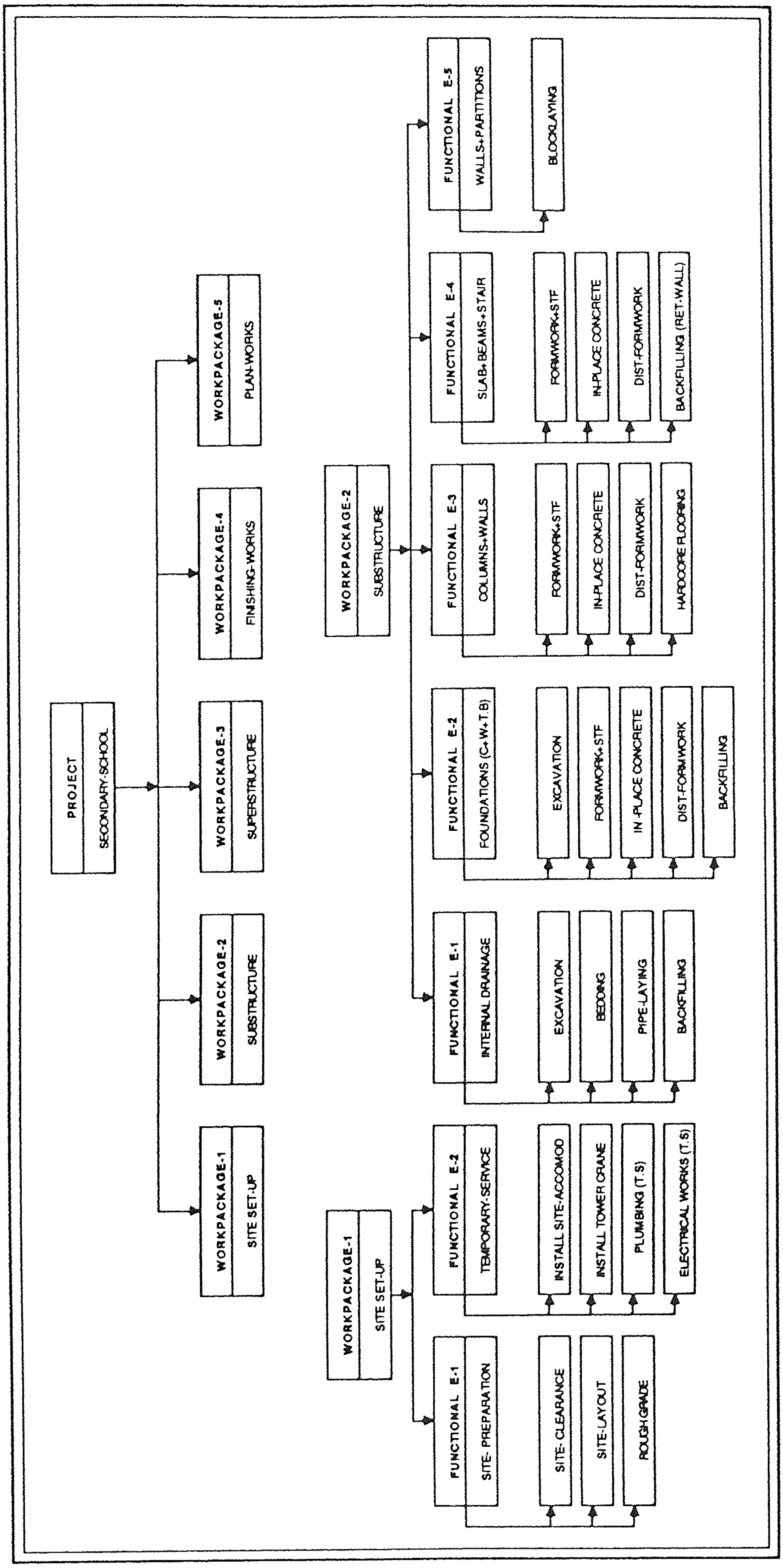

Figure (8)- Project Breakdown Structure (PBS) Chart.

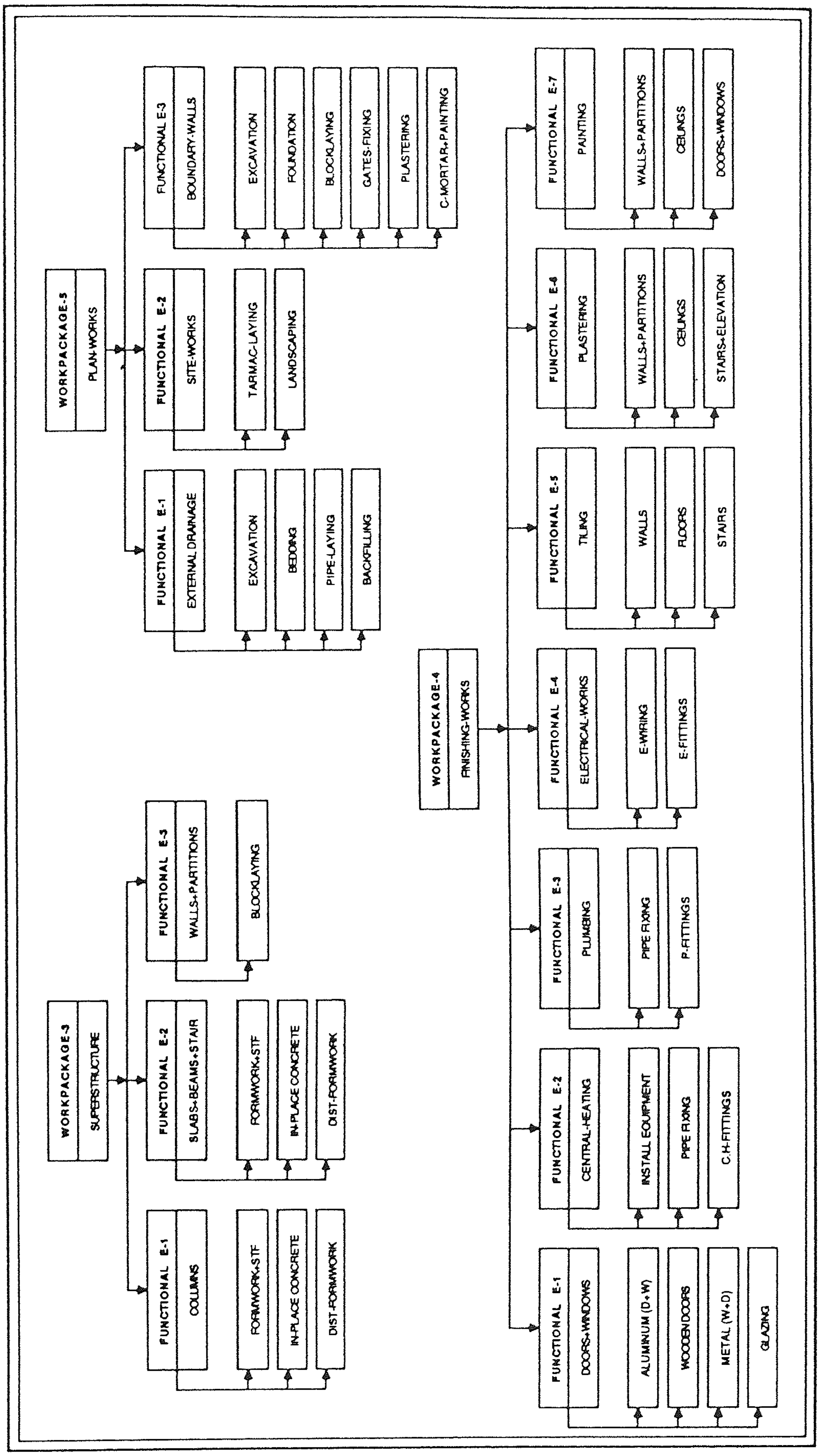

Figure (8)- Continued.

SEQ	RESOUCE DESCRIPTION	CREW MAKE	COST/DAY
1	SITE EXCAVATION	(1)-(J.C.B-4) FRONT BUCKET +DRIVER (2)-(LORRIES)+DRIVERS (2)-LABOURERS	£ 2600
2	EXCAVATION (DRAINAGE+BOUNDARY WALL-FOUNDATION)	(1)-(J.C.B-4) REAR BACK ACTER BUCKET+DRIVER (1)-LABOURER	£ 1200
3	BACKFILLING (DRAINAGE+BASEMENT FLOOR)	(1)-DUMPER+DRIVER (2)-BOB-CAT+DRIVERS (2)-SMALL COMPACTORS+OP (2)-LABOURERS	£ 1600
4	BACKFILLING (RETAINING WALL)	(1)-(J.C.B-4) FRONT BUCKET +DRIVER (1)-ROLLER COMPACTOR+DRIVER (2)-LABOURERS	£1900
5	BOUNDARY-WALLL FOUNDATION	(1)-DUMPER+DRIVER (2)-BOB-CAT+DRIVERS (1)-ROTATING-DRUM TRUCK+DR (2)-LABOURERS	£ 2000
6	PLACING CONCRETE (SMALL JOBS)	(1)-ROTATING-DRUM TRUCK+DR (1)-VIBRATOR+OPERATOR (3)-LABOURERS	£ 1200
7	PLACING CONCRETE (BIG JOBS)	(2)-ROTATING-DRUM TRUCK+DR (2)-VIBRATORS+OPERATORS (5)-LABOURERS	£ 2100

Figure (9)- Details Of Machinery Resources.

SEQ	RESOURCE DESCRIPTION	GANG MAKE UP	COST/DAY
1	SURVEYING	(2)-SURVEYORS (2)-LABOURER	£ 250
2	CARPENTRY (SITE-ACCOMODATION)	(1)-CARPENTER CLASS- (2)-CARPENTERS CLASS-2 (2)-LABOURERS	£ 350
3	ELECTRICAL WORKS (TEMP-SERVICE)	(2)-ELECTRICIANS (1)-LABOURER	£ 250
4	PLUMBING (TEMP-SERVICE+DRAINAGE)	(1)-PLUMBER (1)-LABOURER	£ 150
5	TOWER CRANE INSTALLATION	(2)-MECHANICIAN (1)-ELECTRICIAN (2)-LABOURERS	£ 550
6	FORMWORK+STEEL-FIXING (SUBSTRUCTURE)	(4)-CARPENTERS (3)-STEEL FIXERS (4)-LABOURERS	£ 1000
7	FORMWORK+STEEL-FIXING (SUPERSTRUCTURE)	(6)-CARPENTERS (3)-STEEL FIXERS (6)-LABOURERS	£ 1200
8	FORMWORK DISMANTLING	(2)-CARPENTERS (2)-LABOURERS	£ 300
9	HOIST INSTALLATION	(1)-MECHANICIAN (1)-ELECTRICIAN (2)-LABOURERS	£ 300
10	BLOCKLAYING	(1)-BLOCKLAYER (1)-LABOURER	£ 150
11	ELECTRICAL WORKS	(1)-ELECTRICIAN (1)-LABOURER	£ 150
12	METAL WINDOWS+DOORS	(1)-TRADESMAN CLASS-1 (1)-TRADESMAN CLASS-2	£ 200
13	WOODEN DOORS	(1)-TRADESMAN CLASS-1 (1)-TRADESMAN CLASS-2	£ 200
14	ALUMINUM WINDOWS+DOORS	(1)-TRADESMAN (1)-LABOURER	£ 150
15	PLUMBING	(1)-PLUMBER (1)-LABOURER	£ 150
16	CENTRAL HEATING	(4)-TRADEMEN	£ 400
17	PLASTER	(1)-PLASTERER (1)-LABOURER	£ 150
18	TILING	(1)-TILER (1)-LABOURER	£ 150
19	GLAZING	(1)-TRADESMAN (1)-LABOURER	£ 150
20	PAINTING	(1)-PAINTER (1)-LABOURER	£ 150
21	LABOURING JOBS	(1)-LABOURER	£ 50

Figure (10)- Details Of Labour Resources.

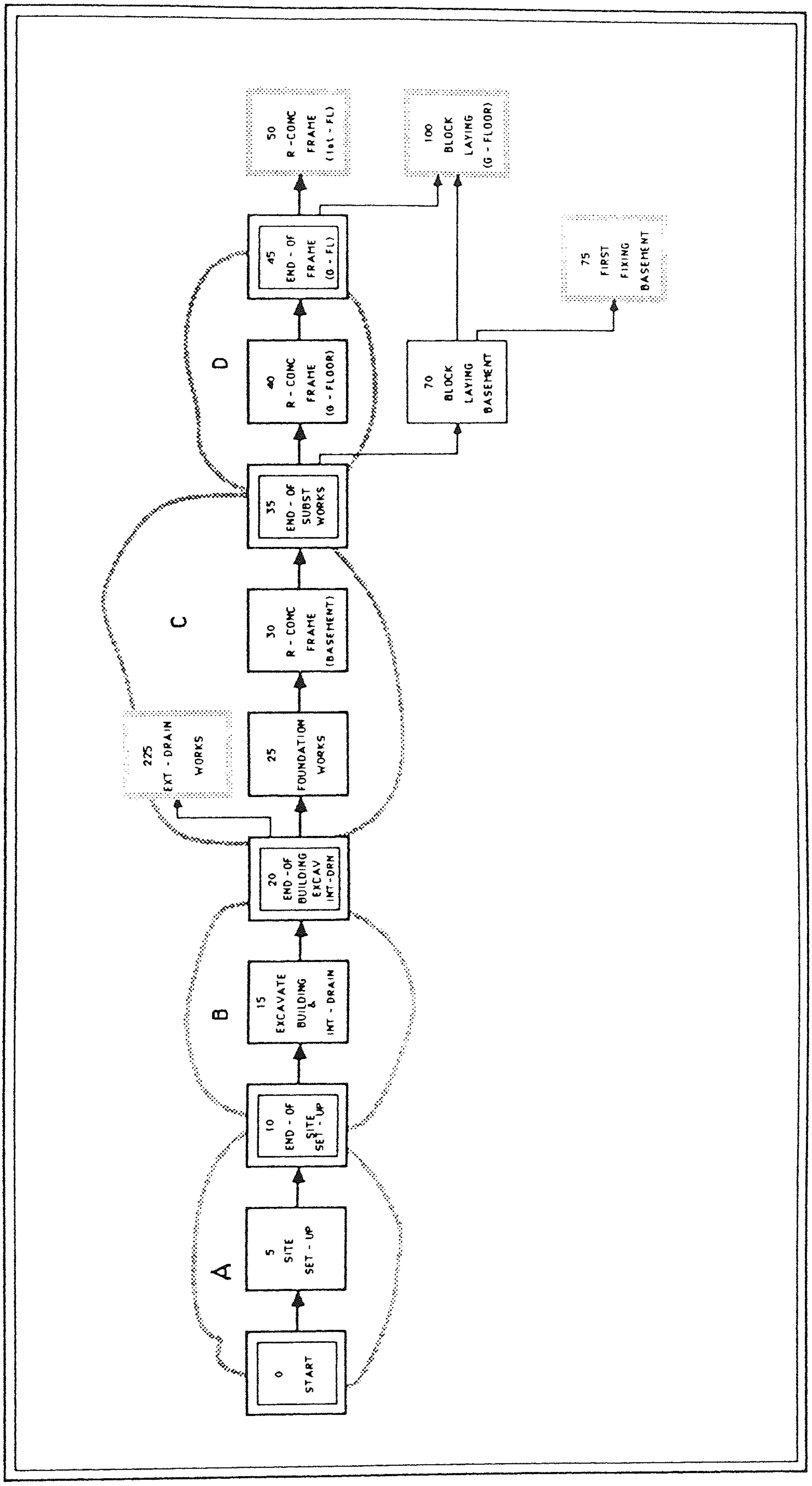

Figure (11)- Master Plan (C.P.M).

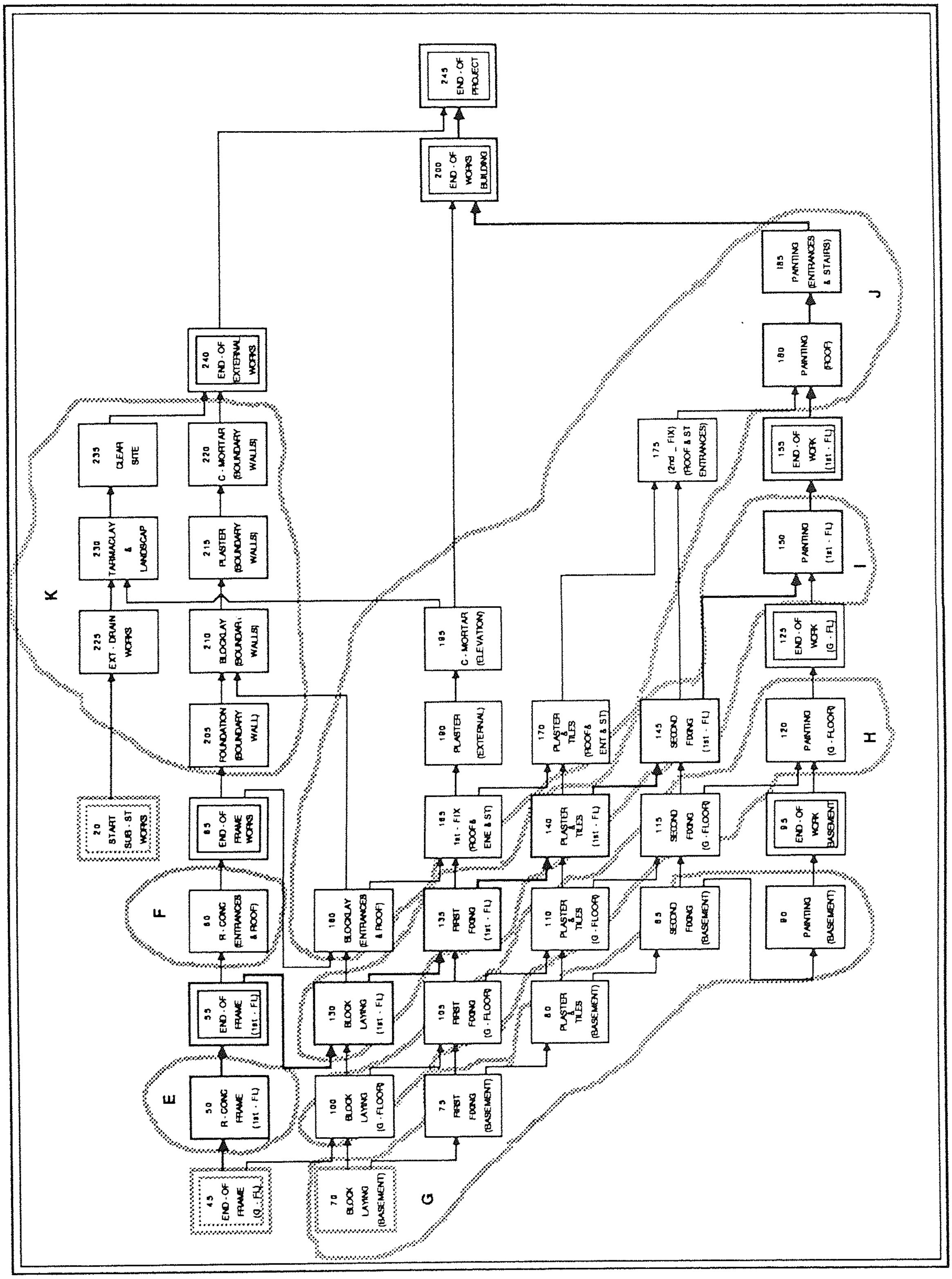

Figure (11)- Continued.

SERIAL-NO	NODE-NO	ACTIVITY-DESCRIPTION	PRECEDING NODES	SUCCEEDING NODES	DURATION	EARLY-ST	EARLY-FINISH	LATE-START	LATE-FINISH	TOTAL-FLT	FREE-FLT	C.P
1	0	**Start**	-	5	0	0	0	0	0	0	0	*
2	5	Site - Set-up	0	10	16	0	16	0	16	0	0	*
3	10	**End Of Site - Set-up**	5	15	0	16	16	16	16	0	0	*
4	15	Excavate For (Build+Int-Drain)	10	20	16	16	32	16	32	0	0	*
5	20	**End Of Building Excav+Int-D**	15	25,225	0	32	32	32	32	0	0	*
6	25	Foundation-works	20	30	26	32	58	32	58	0	0	*
7	30	R-Concrete-Frame (Basement)	25	35	41	58	99	58	99	0	0	*
8	35	**End Of Substructure Works**	30	40,70	0	99	99	99	99	0	0	*
9	40	R-Concrete-Frame (G-Floor)	35	45	32	99	131	99	131	0	0	*
10	45	**End Of R.c.Frame (G-Floor)**	40	50,100	0	131	131	131	131	0	0	*
11	50	R-Concrete-Frame (1st-Floor)	45	55	32	131	163	131	163	0	0	*
12	55	**End Of R.C.Frame (1st-Floor)**	50	60,130	0	163	163	163	163	0	0	*
13	60	R.C.Frame (entrance+Roof)	55	65	12	163	175	185	197	22	0	
14	65	**End Of Frameworks**	60	160,205	0	175	175	197	197	22	0	
15	70	Blocklaying (Basement)	35	75,100	10	99	109	136	146	37	0	
16	75	1ST-Fixing (Basement)	70	80,105	14	109	123	146	160	37	0	
17	80	Plaster+Tiles (Basement)	75	85,110	18	123	141	160	178	37	0	
18	85	2nd-Fixing (Basement)	80	90,115	11	141	152	182	193	41	0	
19	90	Painting(Basement)	85	95	9	152	161	209	218	57	0	
20	95	**End Of Work(Basement)**	90	120	0	161	161	218	218	57	31	
21	100	Blocklaying(G - Floor)	45,70	105,130	17	131	148	146	163	15	0	
22	105	1st - Fixing(G - Floor)	75,100	110,135	12	148	160	166	178	18	0	
23	110	Plaster + Tiles(G - Floor)	80,105	115,140	15	160	175	178	193	18	0	
24	115	2nd - Fixing(G - Floor)	85,110	120,145	17	175	192	193	210	18	0	
25	120	Painting(G - Floor)	95,115	125	9	192	201	218	227	26	0	
26	125	**End Of Work(G - Floor)**	120	150	0	201	201	227	227	26	26	
27	130	Blocklaying(1st - Floor)	55,100	135,160	20	163	183	163	183	0	0	*
28	135	1st - Fixing(1st - Floor)	105,130	140,165	12	183	195	183	195	0	0	*
29	140	Plaster + Tiles(1st - Floor)	110,135	145,170	15	195	210	195	210	0	0	*
30	145	2nd Fixing(1st - Floor)	115,140	150,175	17	210	227	210	227	0	0	*
31	150	Painting(1st - Floor)	125,145	155	8	227	235	227	235	0	0	*
32	155	**End Of work(1st - Floor)**	150	180	0	235	235	235	235	0	0	*
33	160	Blocklaying(Entrances + St + R)	65,130	165,210	8	183	191	197	205	14	0	
34	165	1st - Fixing(Entrances + St + R)	135,160	170,190	4	195	199	205	209	10	0	
35	170	Plaster + Tiles(Entra + St + R)	140,165	175	16	210	226	215	231	5	1	
36	175	2nd - Fixing(Entrances + St + R)	145,170	180	4	227	231	231	235	4	4	
37	180	Painting(Roof)	155,175	185	4	235	239	235	239	0	0	*
38	185	Painting(Entrances + St)	180	200	6	239	245	239	245	0	0	*
39	190	Plaster(Elevation)	165	195	12	199	211	209	221	10	0	
40	195	C - Mortar - Spray(Elevation)	190	200,230	10	211	221	221	231	10	0	
41	200	**End Of Works(Building)**	185,195	245	0	245	245	245	245	0	0	*
42	205	Foundation(Boundary - Walls)	65	210	5	175	180	208	213	33	11	
43	210	Blocklaying(Boundary - Walls)	205	215	12	191	203	213	225	22	0	
44	215	Plaster (Boundary - Walls)	210	220	12	203	215	225	237	22	0	
45	220	C - Mortar (Boundary - Walls)	215	240	8	215	223	237	245	22	12	
46	225	Drainage - works(External)	20	230	10	32	42	221	231	189	179	
47	230	Tarmac - Laying + Landscaping	195,225	235	10	221	231	231	241	10	0	
48	235	Clear - Site	230	240	4	231	235	241	245	10	0	
49	240	**End Of External works**	220,235	245	0	235	235	245	245	10	10	
50	245	**End Of The Project**	200,240	-	0	245	245	245	245	0	0	*

Figure (12)- Critical Path Analysis Of The Master Plan.

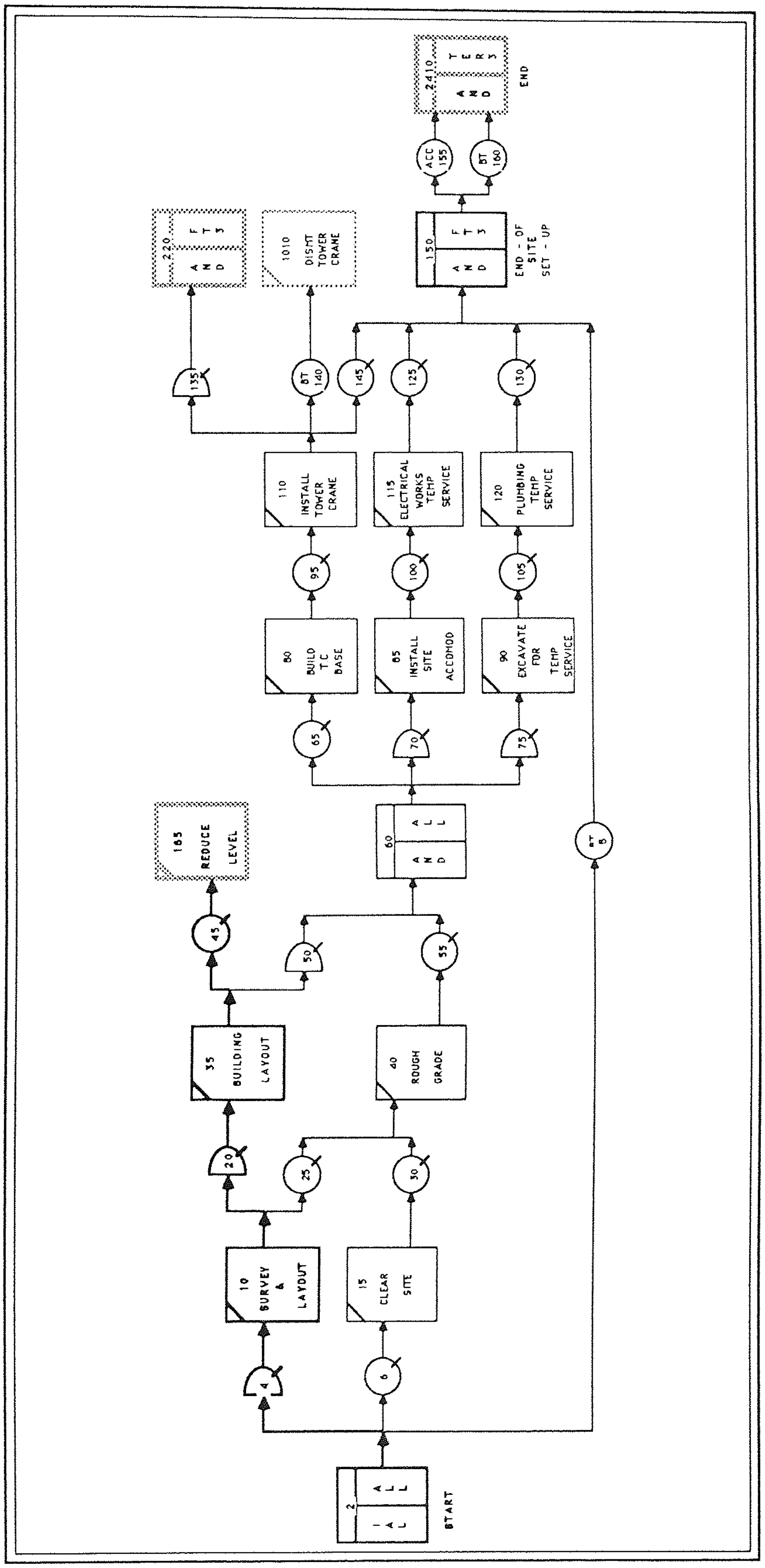

Figure (13)- Detailed Network Of Sub-Network (A).

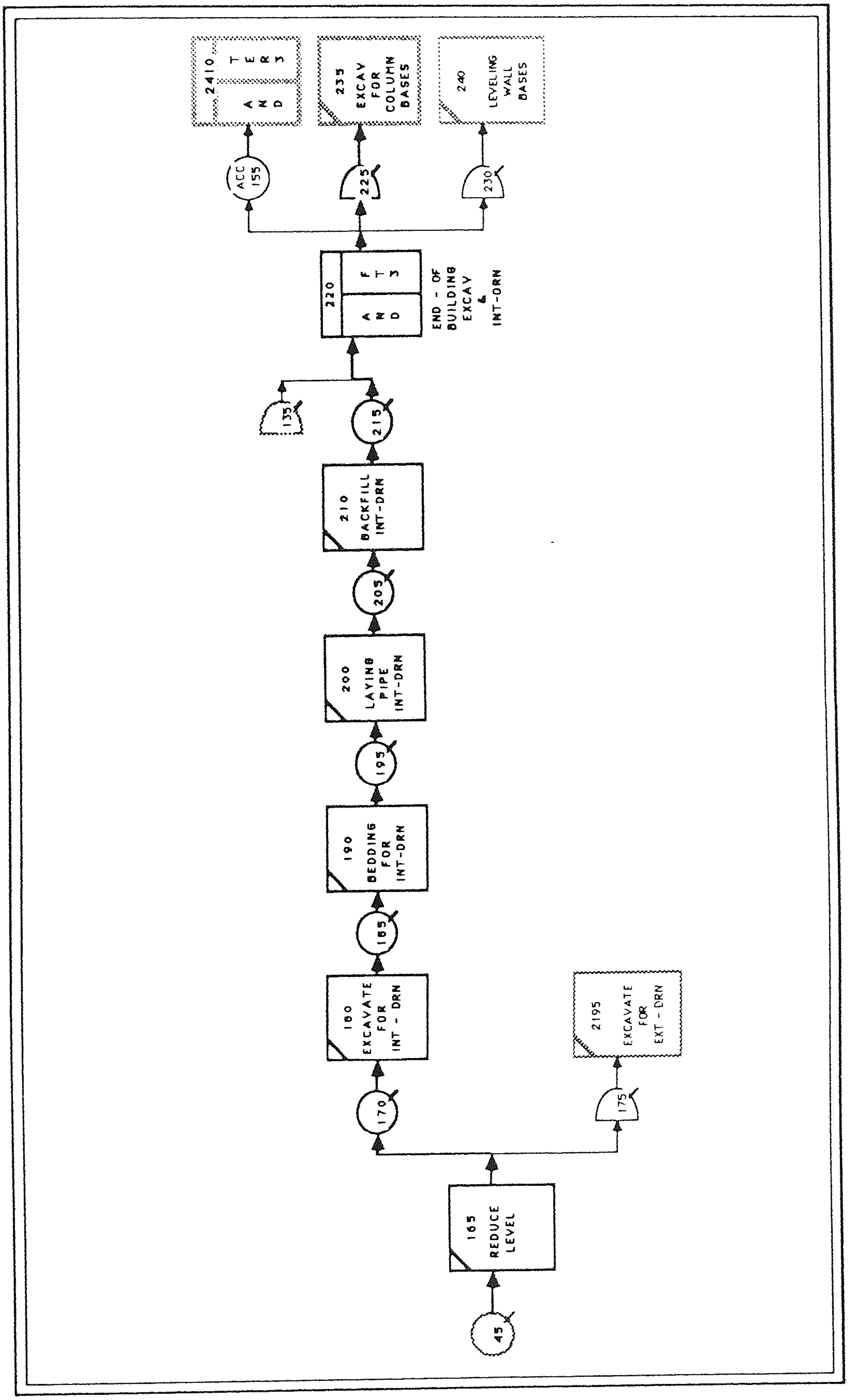

Figure (14)- Detailed Network Of Sub-Network (B).

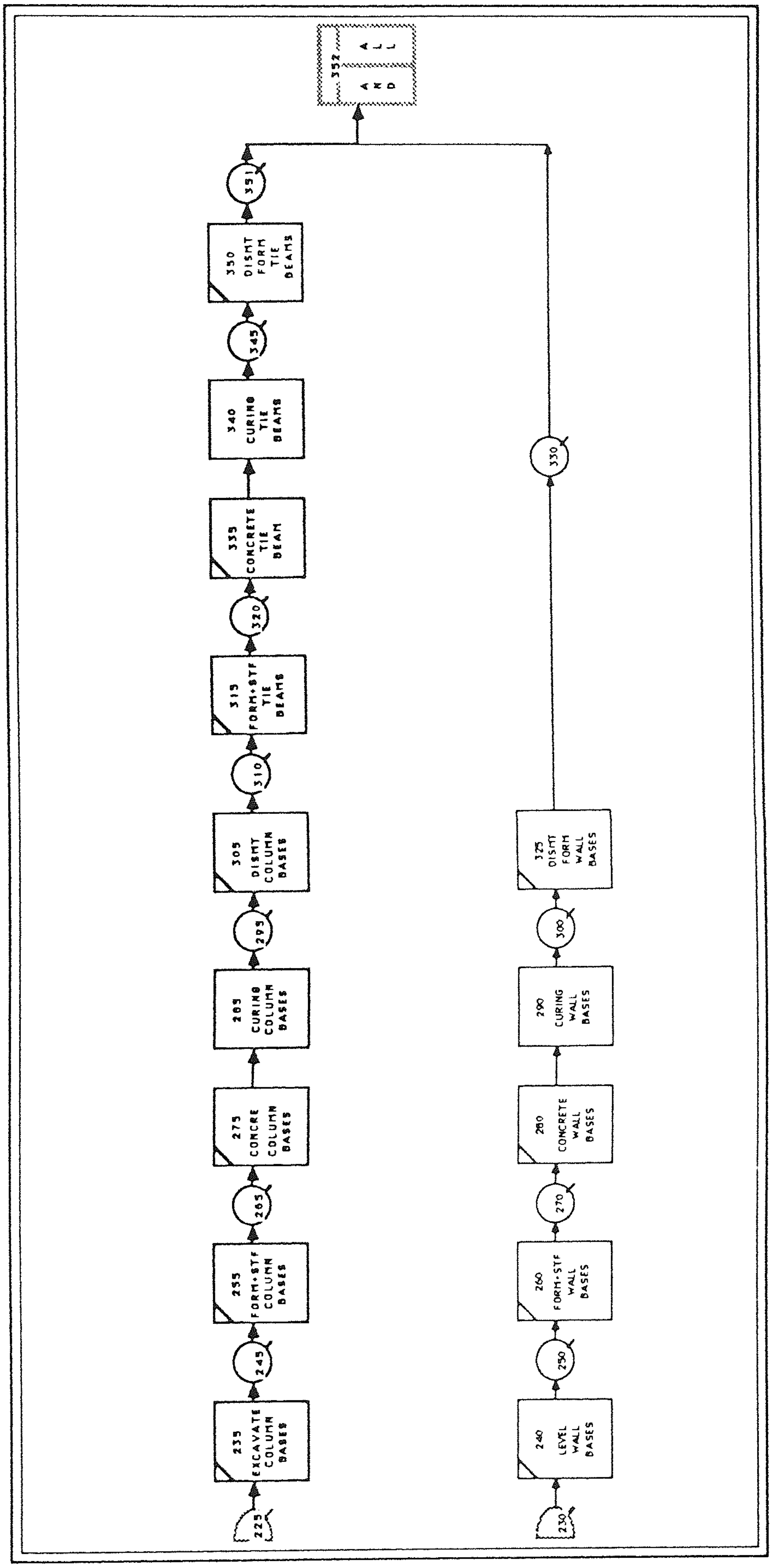

Figure (15)- Detailed Network Of Sub-Network (C).

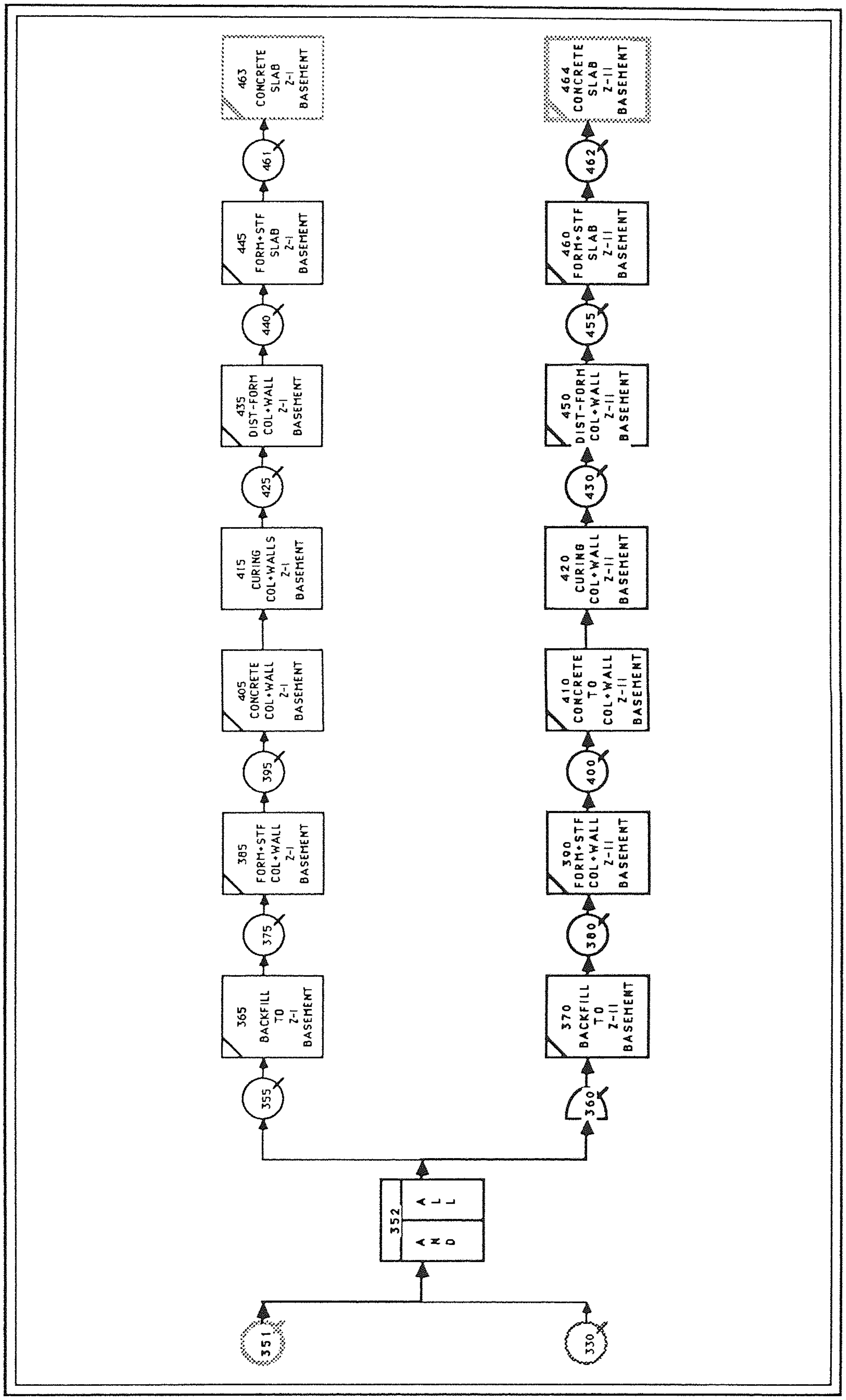

Figure (15)- Continued.

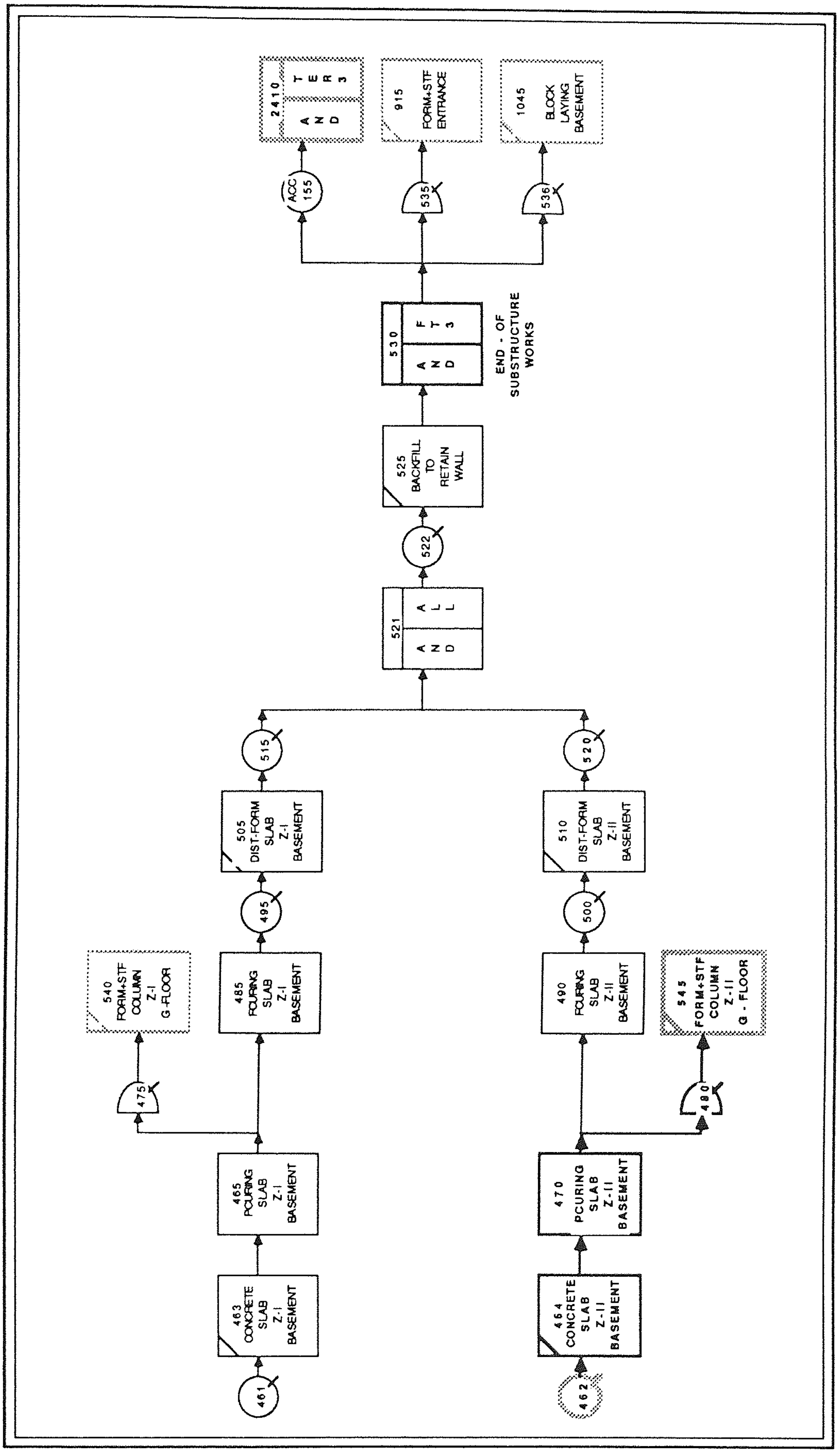

Figure (15)- Continued.

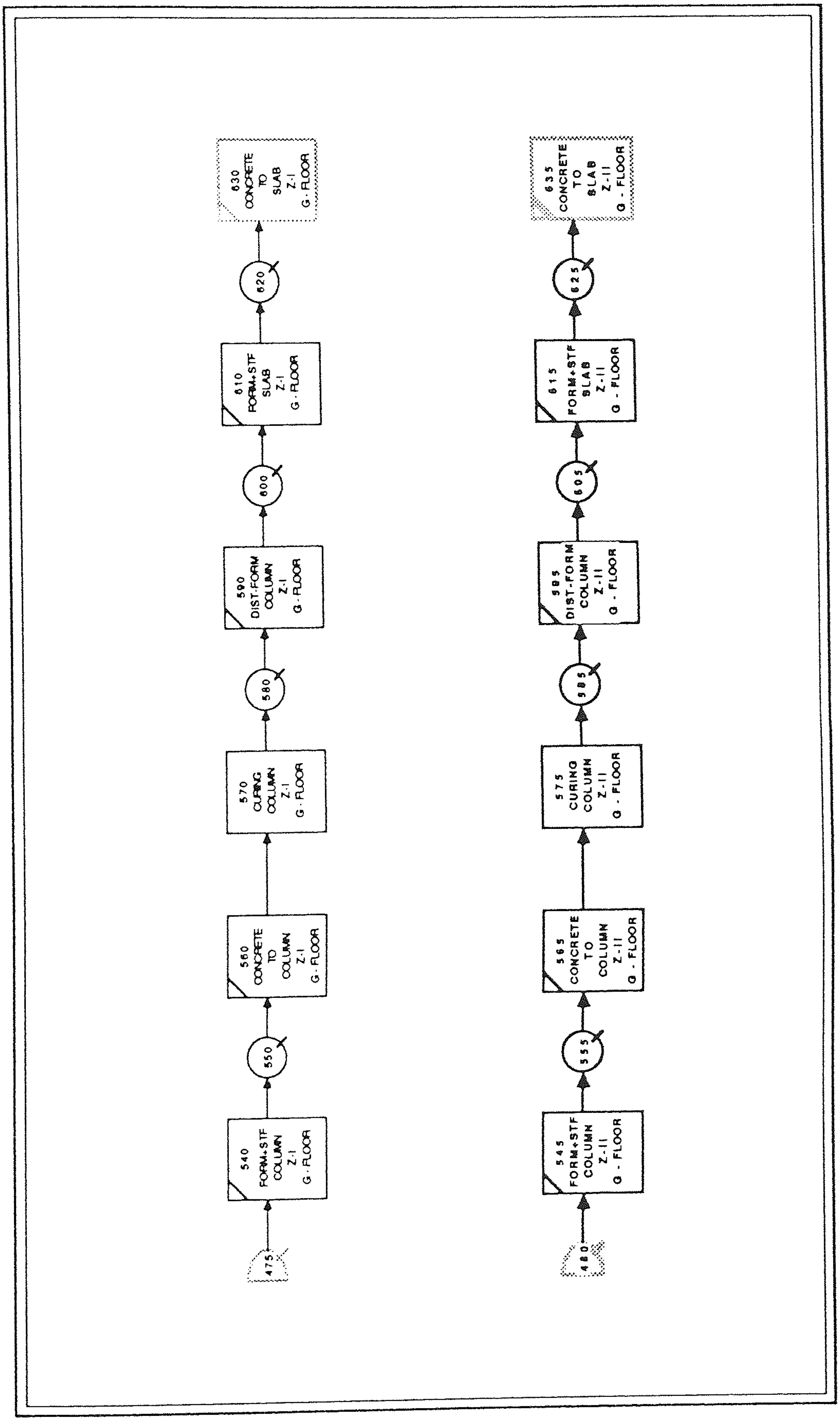

Figure (16)- Detailed Network Of Sub-Network (D).

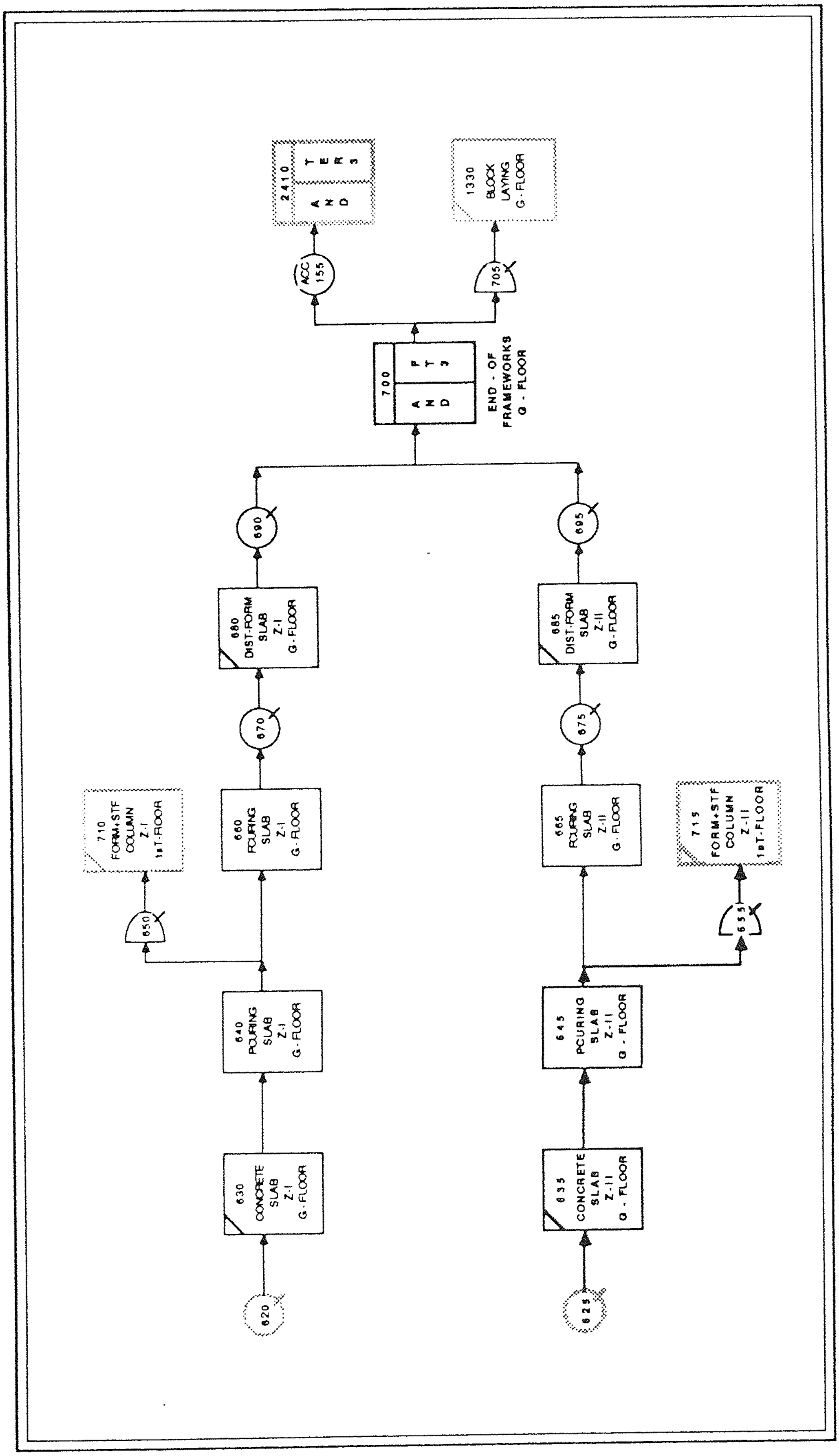

Figure (16)- Contimued.

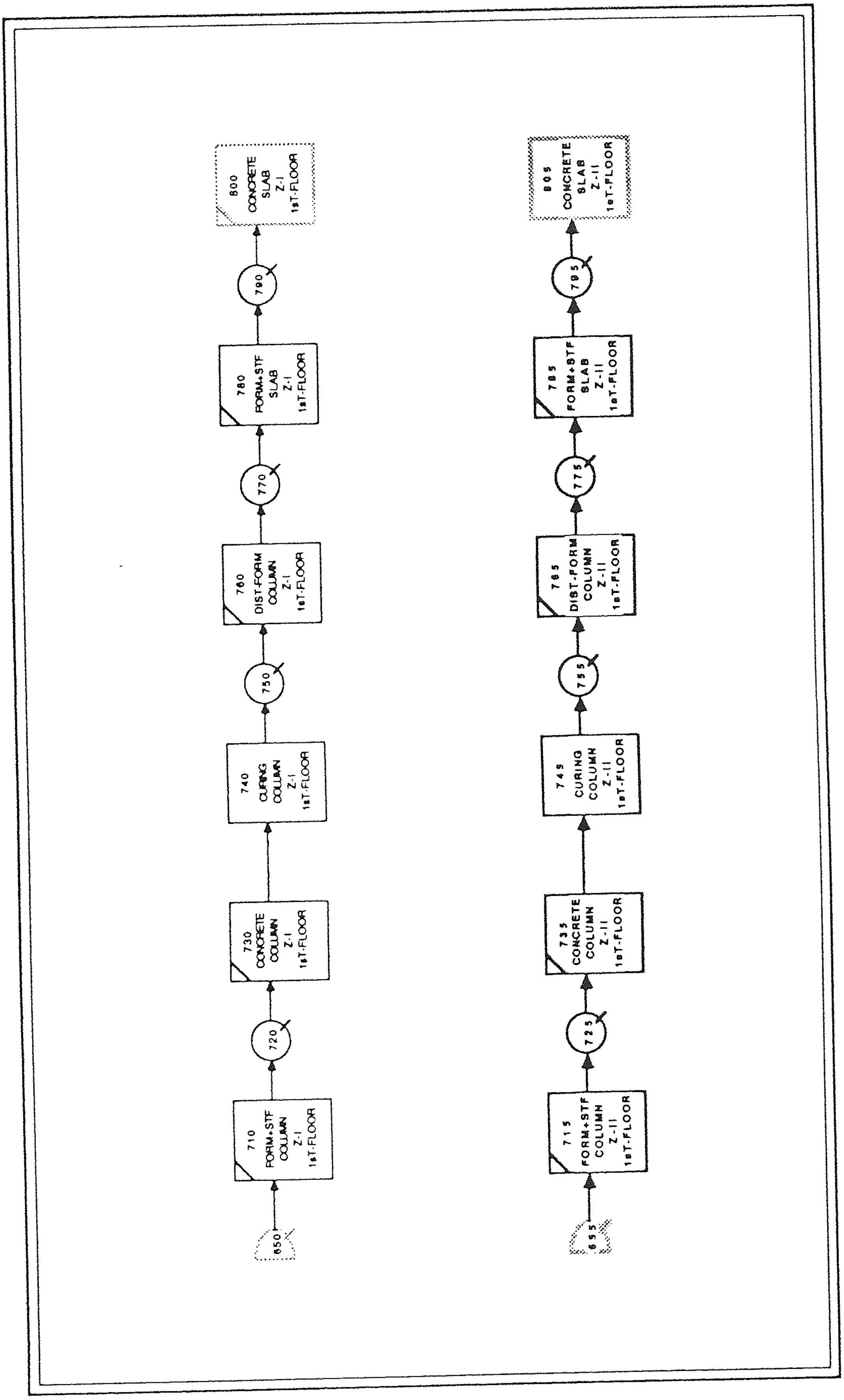

Figure (17)- Detailed Network Of Sub-Network (E).

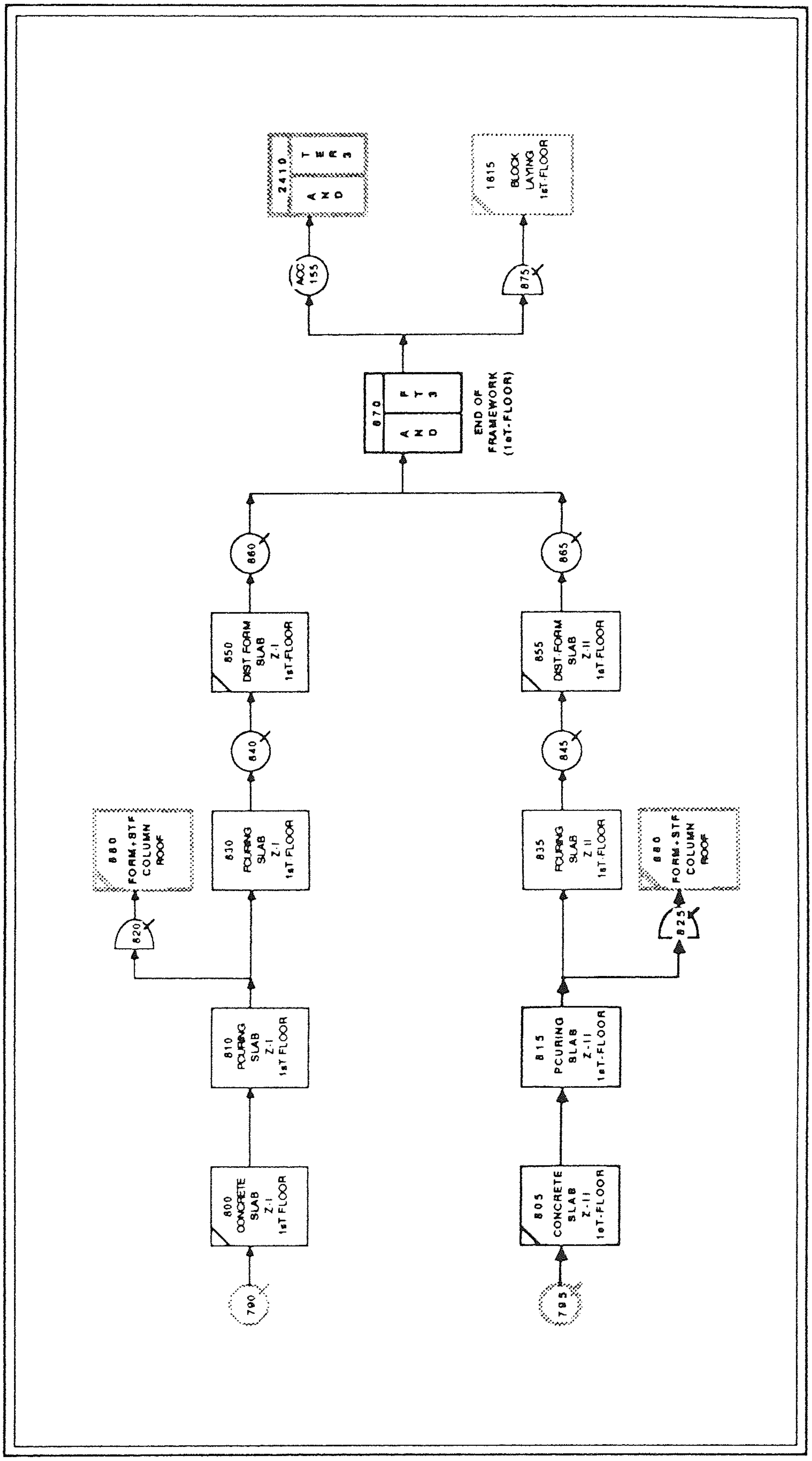

Figure (17)- Continued.

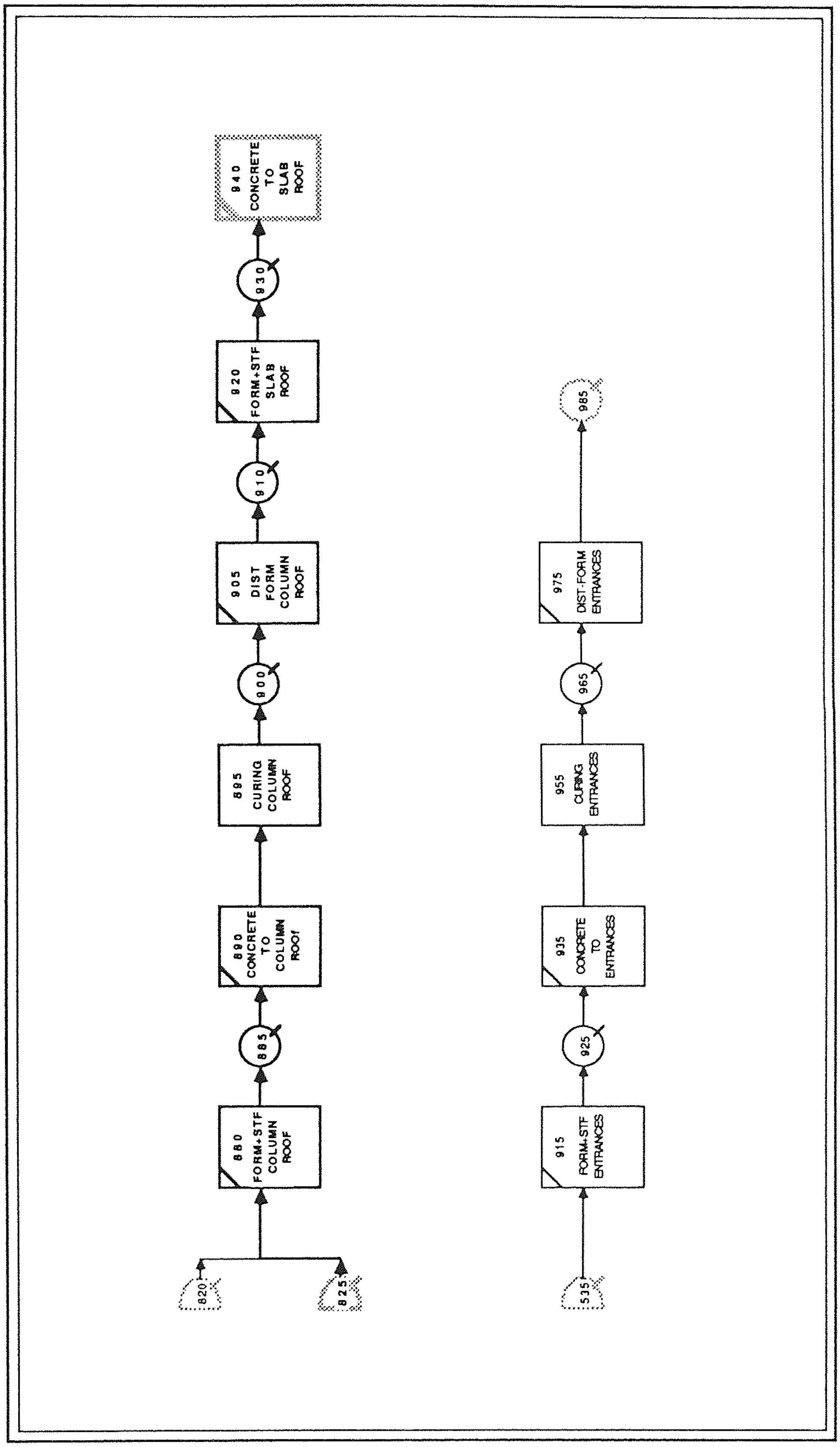

Figure (18)- Detailed Network Of Sub-Network (F).

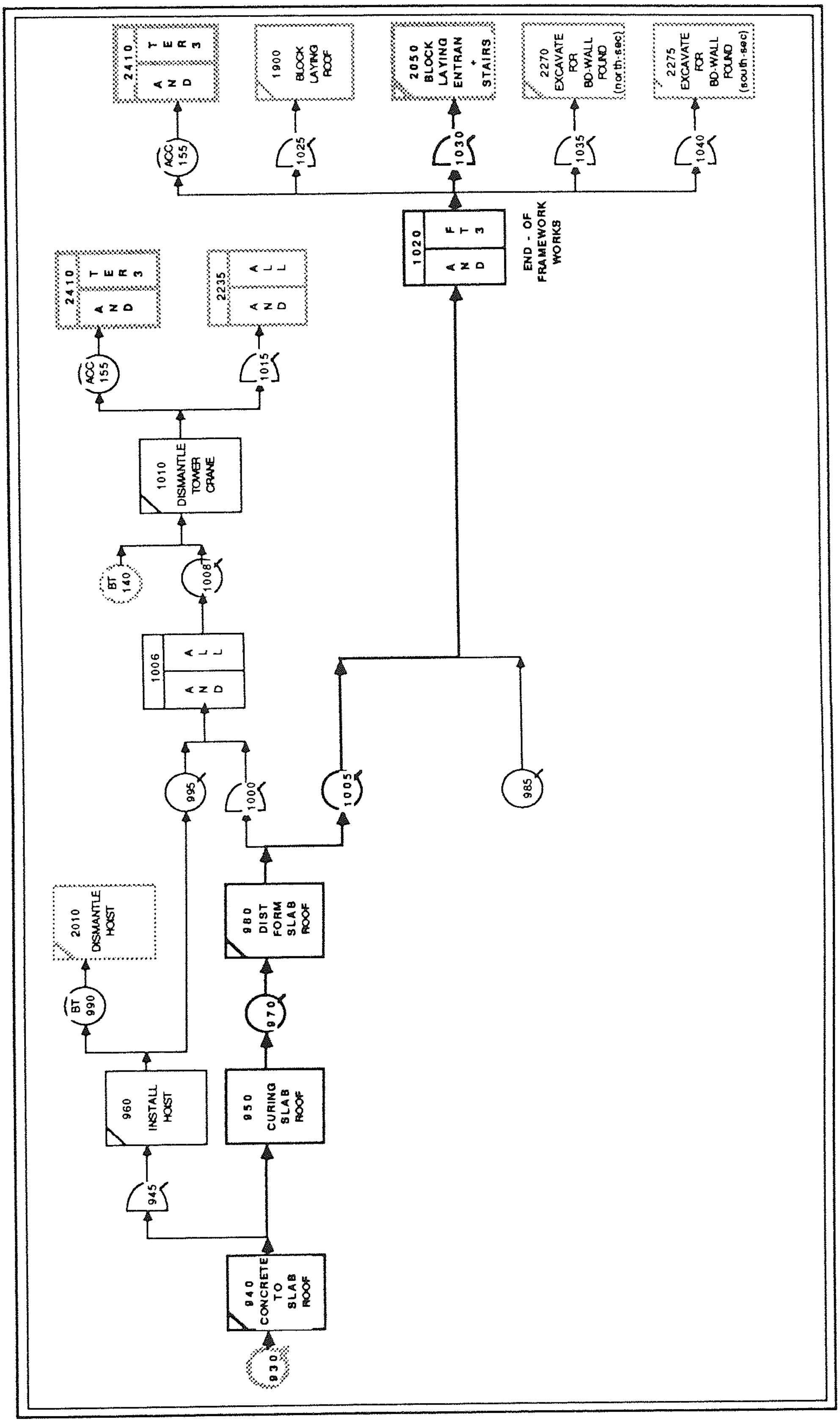

Figure (18)- Continued.

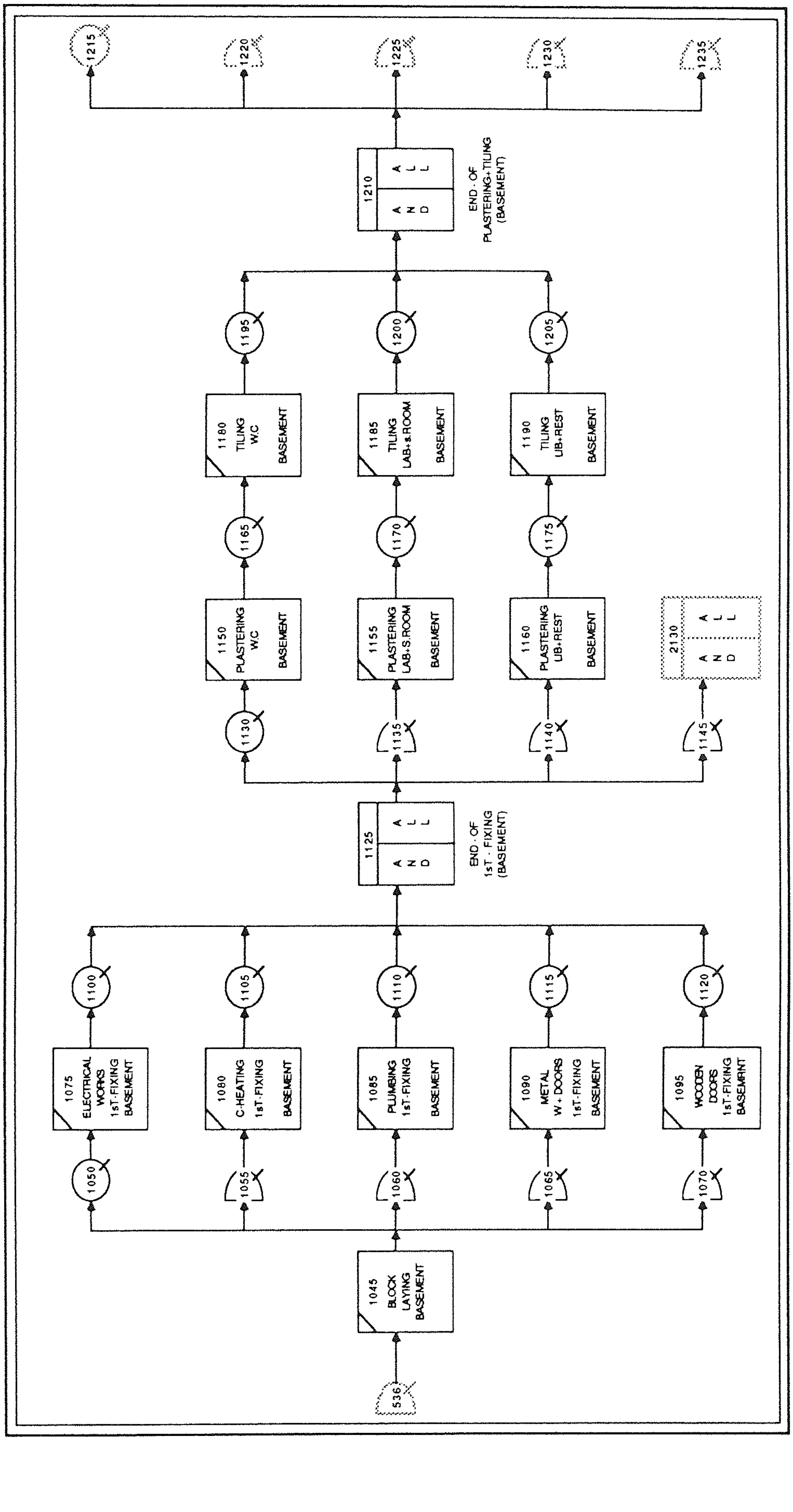

Figure (19)- Detailed Network Of Sub-Network (G).

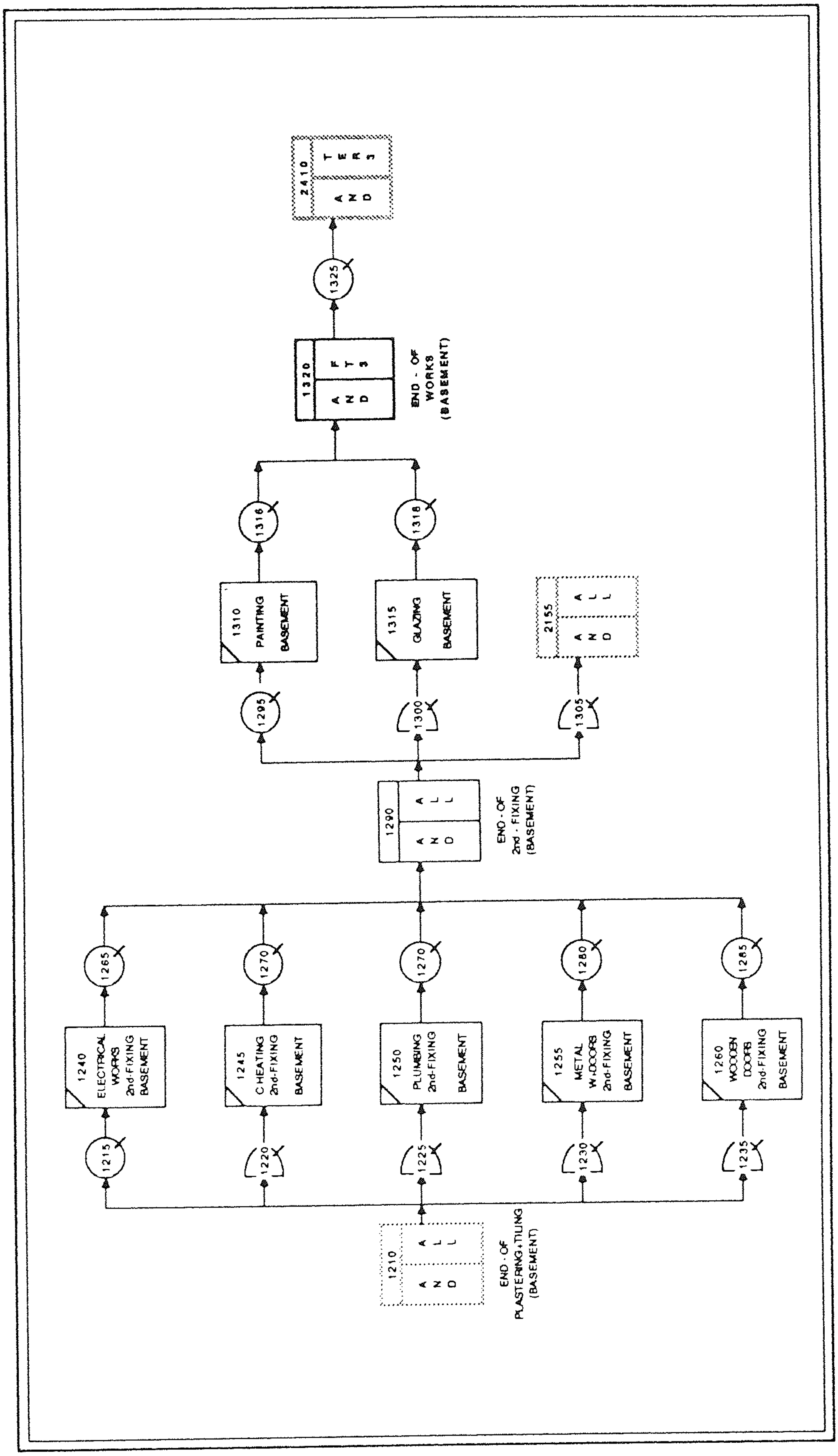

Figure (19)- Continued.

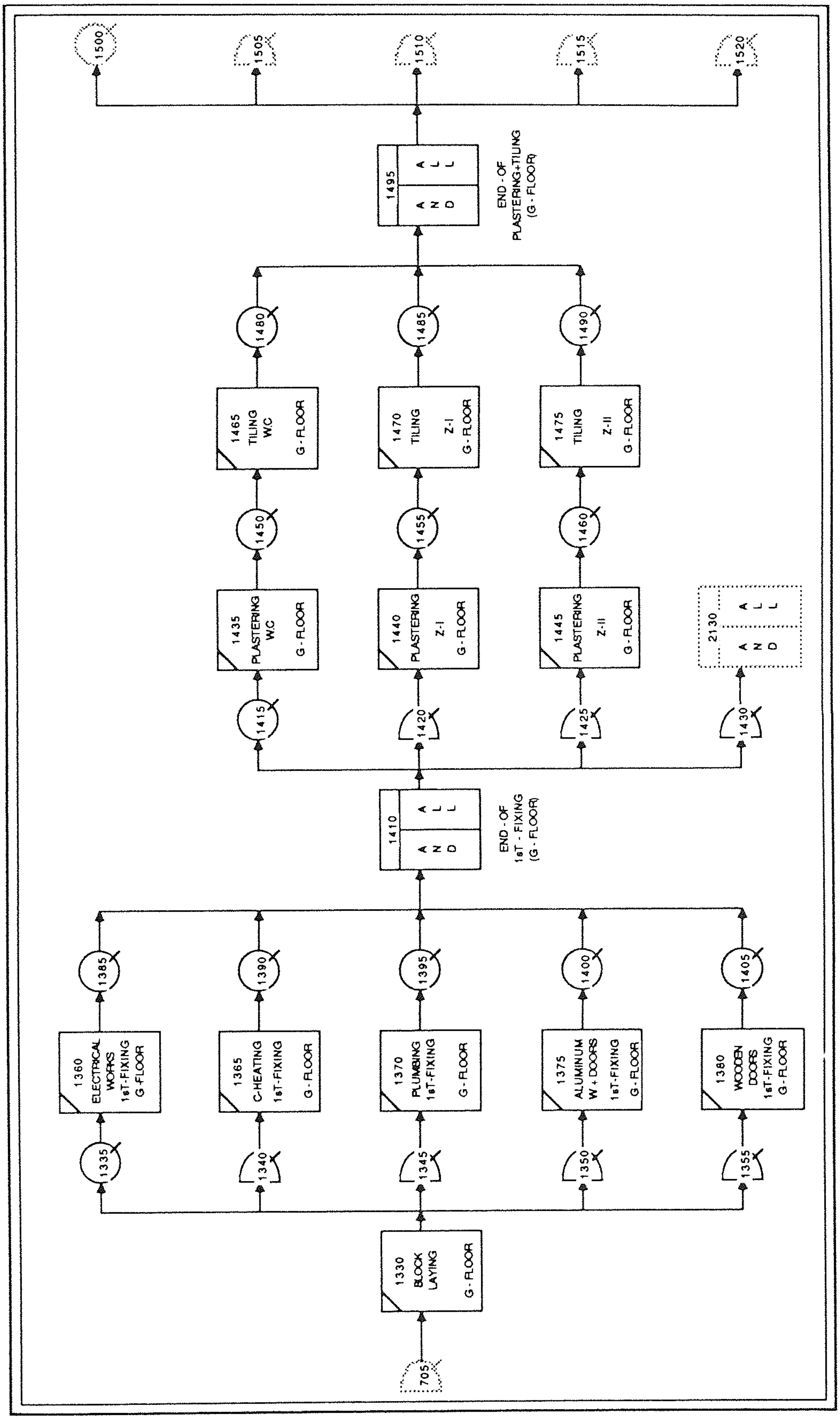

Figure (20)- Detailed Network Of Sub-Network (H).

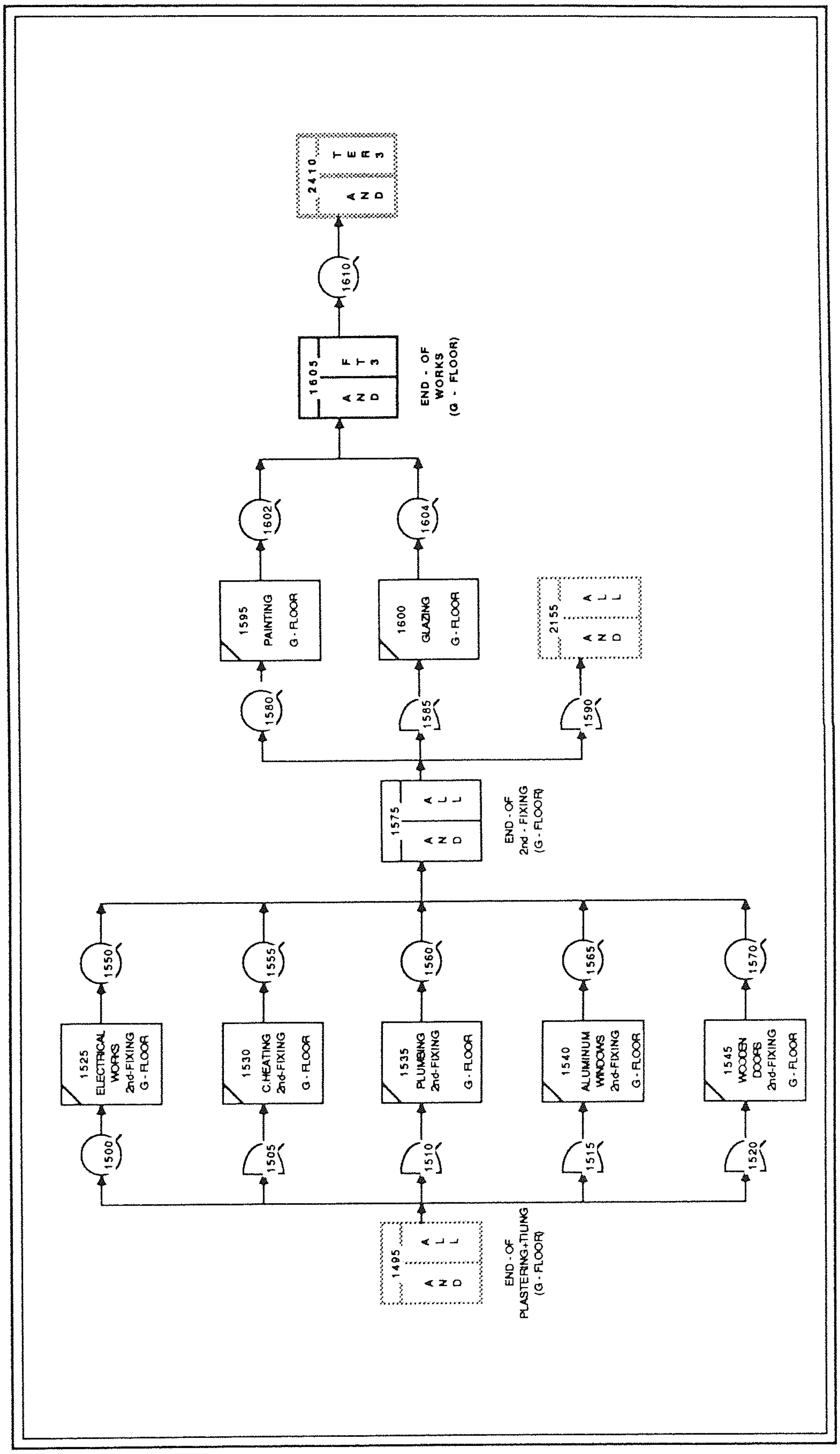

Figure (20)- Continued.

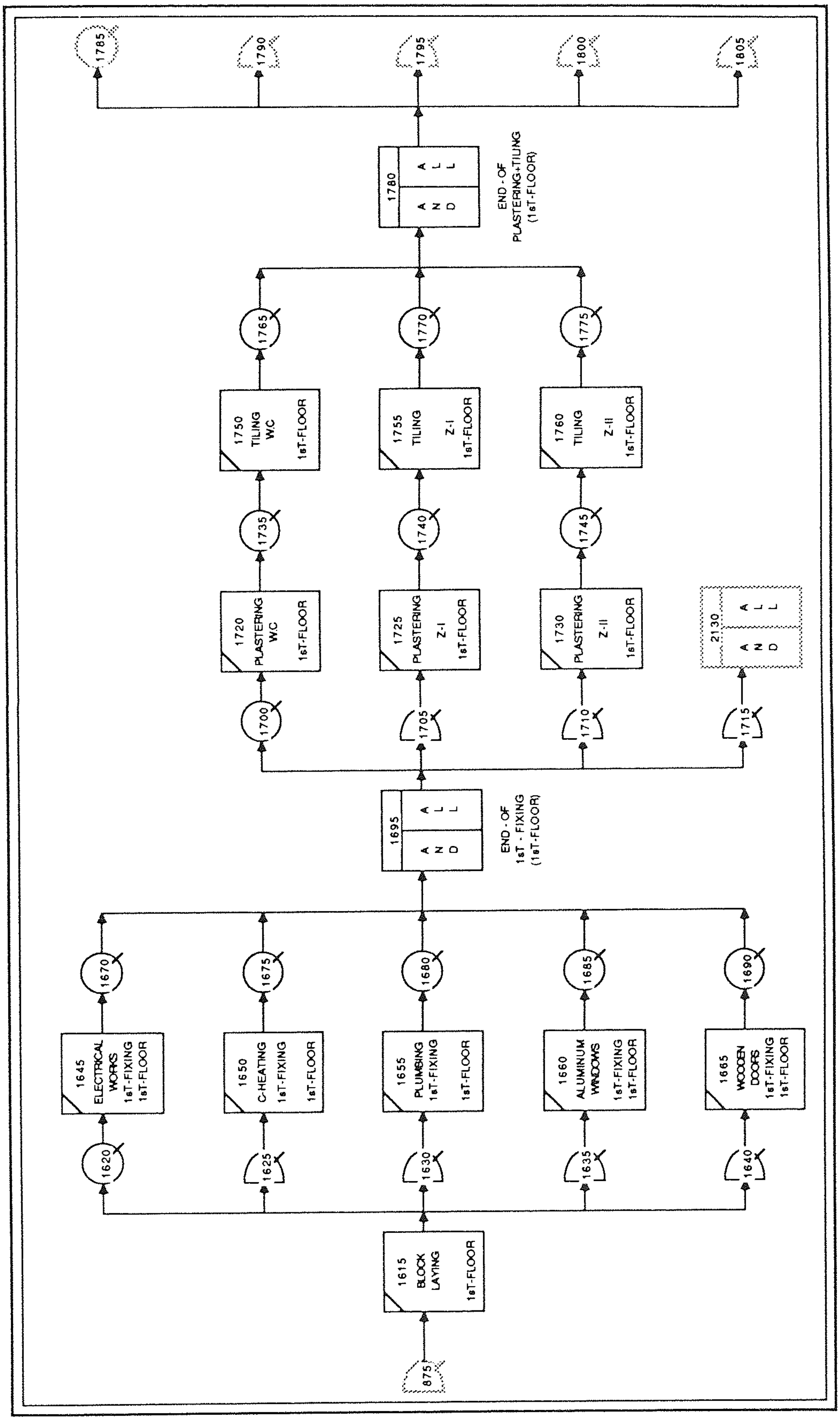

Figure (21)- Detailed Network Of Sub-Network (I).

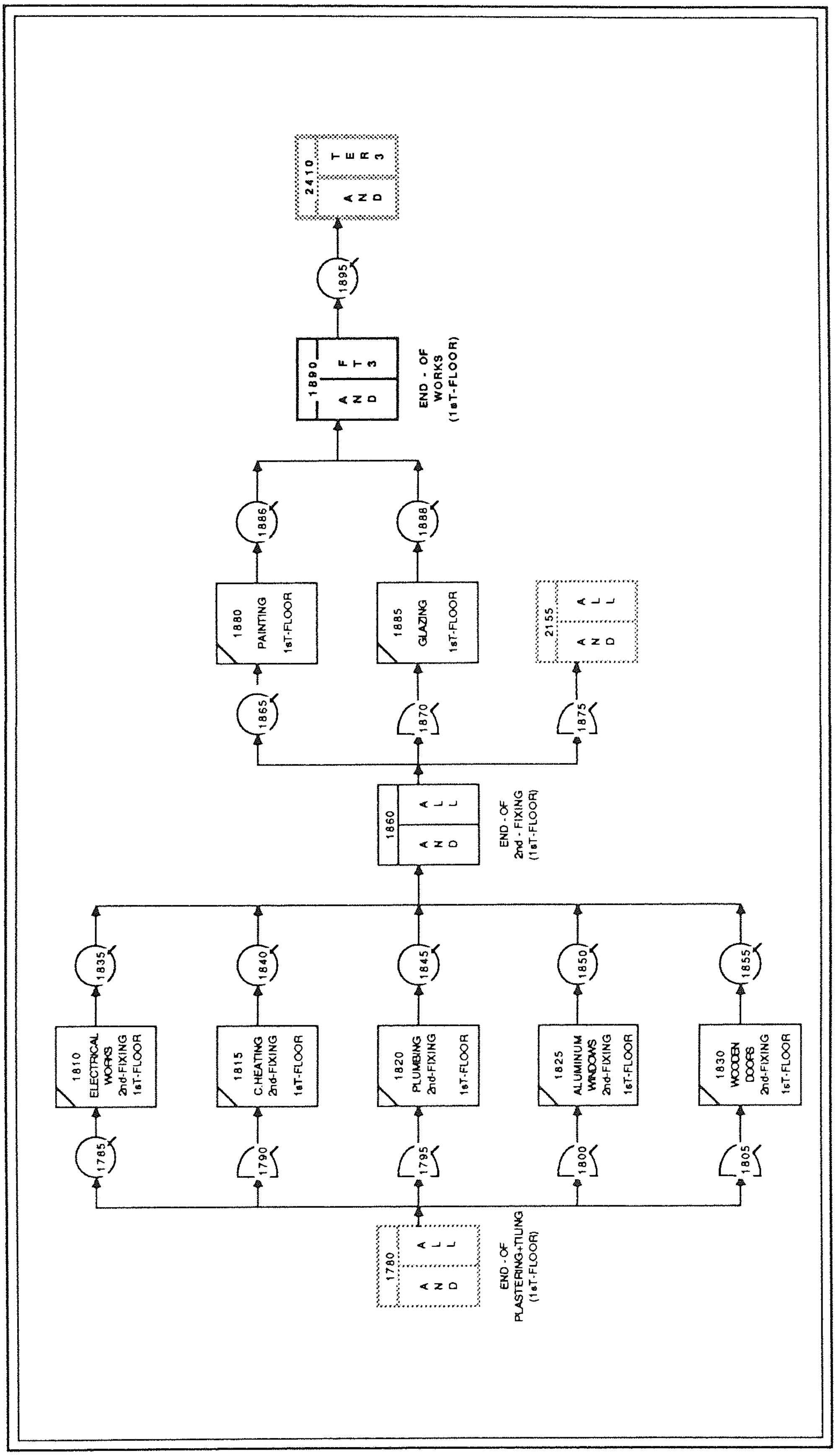

Figure (21)- Continued.

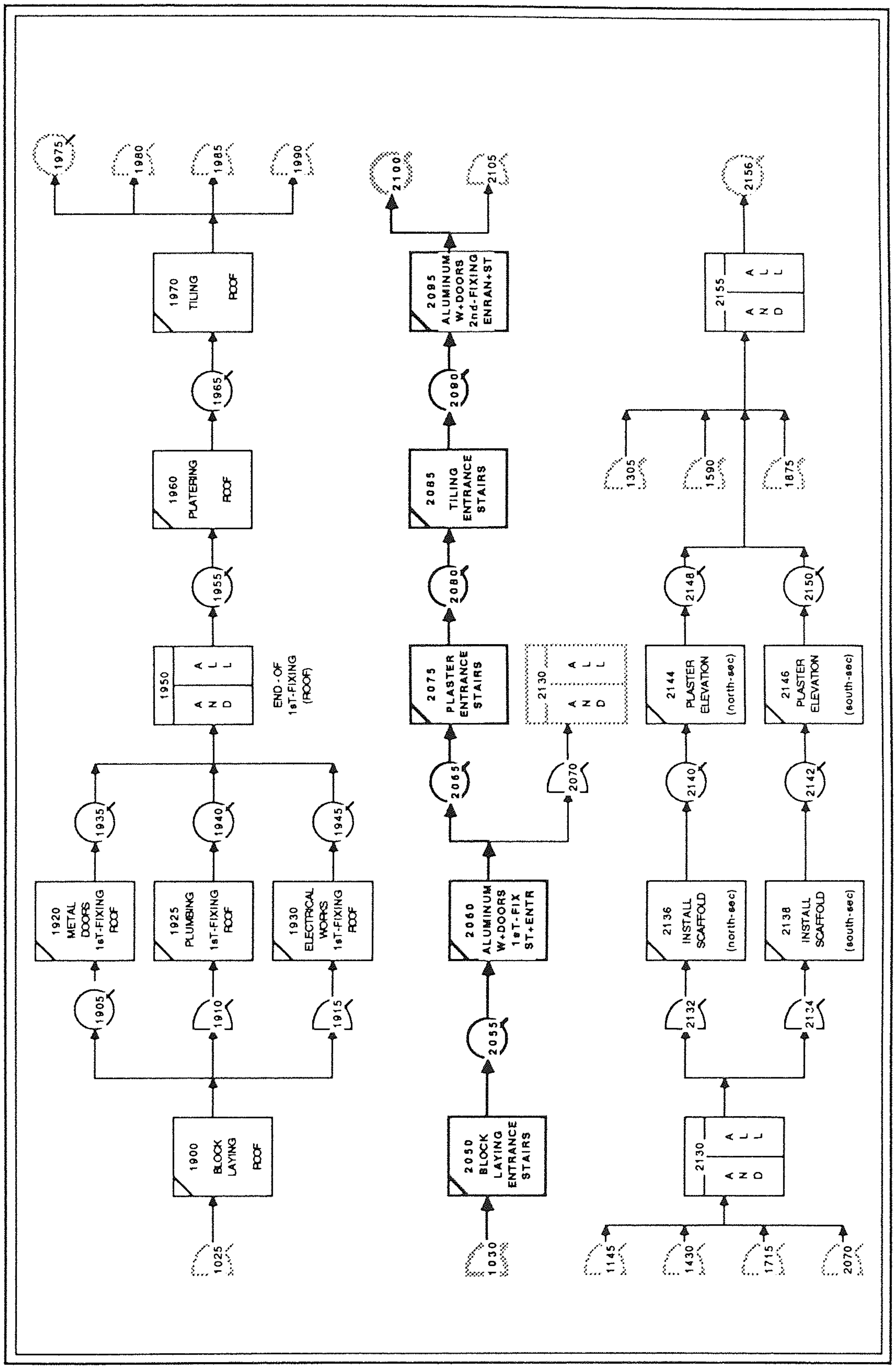

Figure (22)- Detailed Network Of Sub-Network (J).

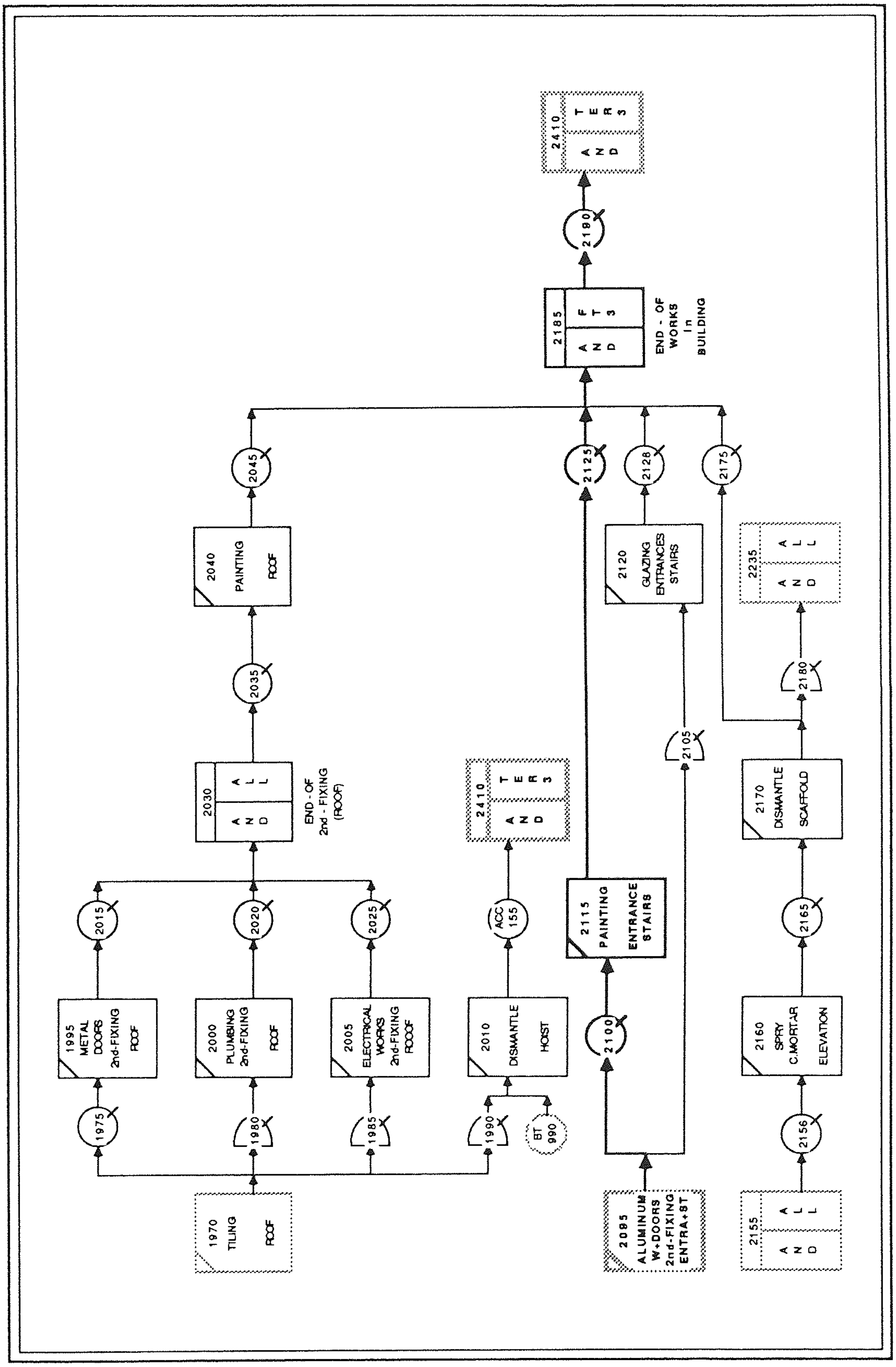

Figure (22)- Continued.

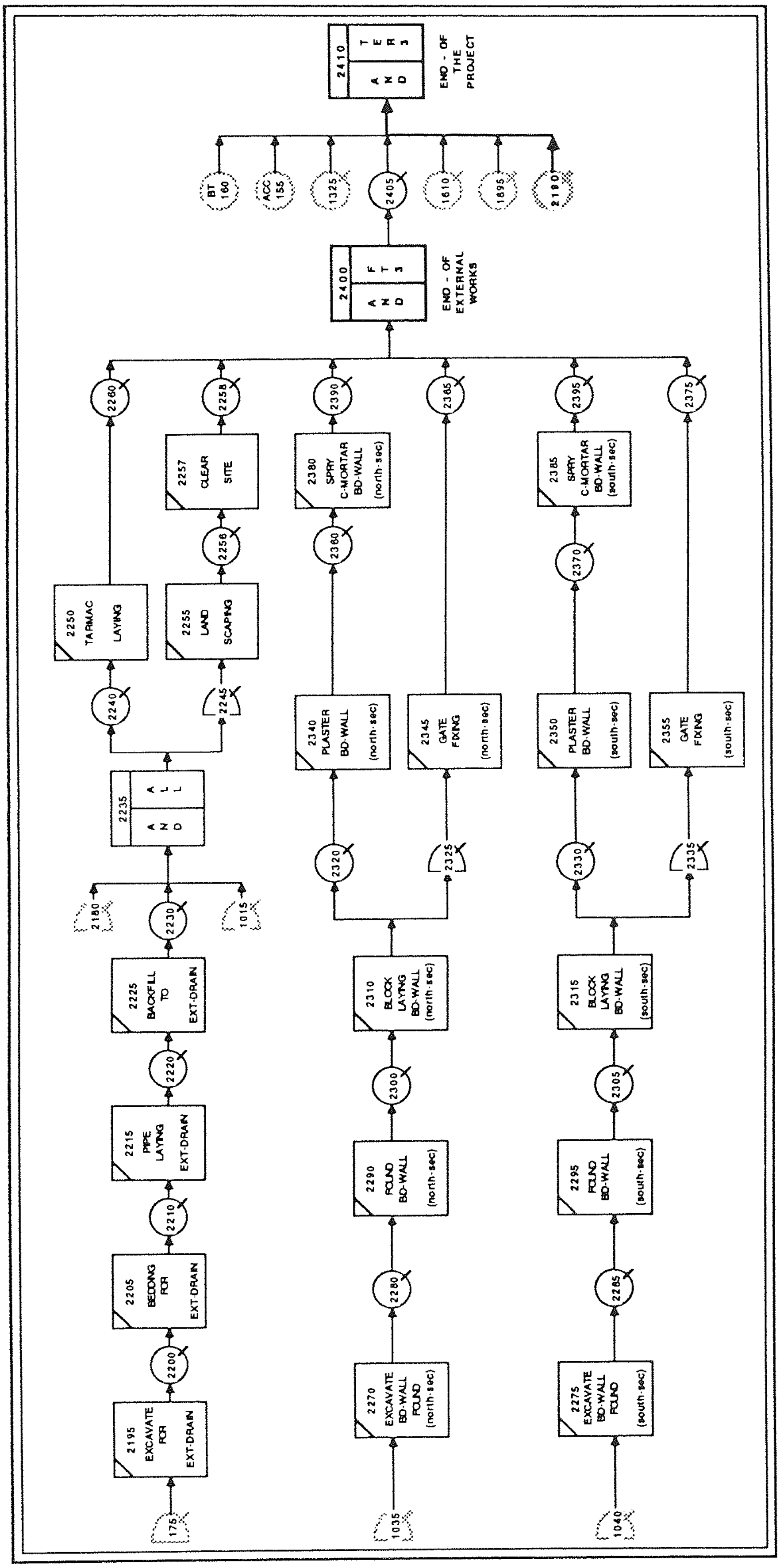

Figure (23)- Detailed Network Of Sub-Network (K).

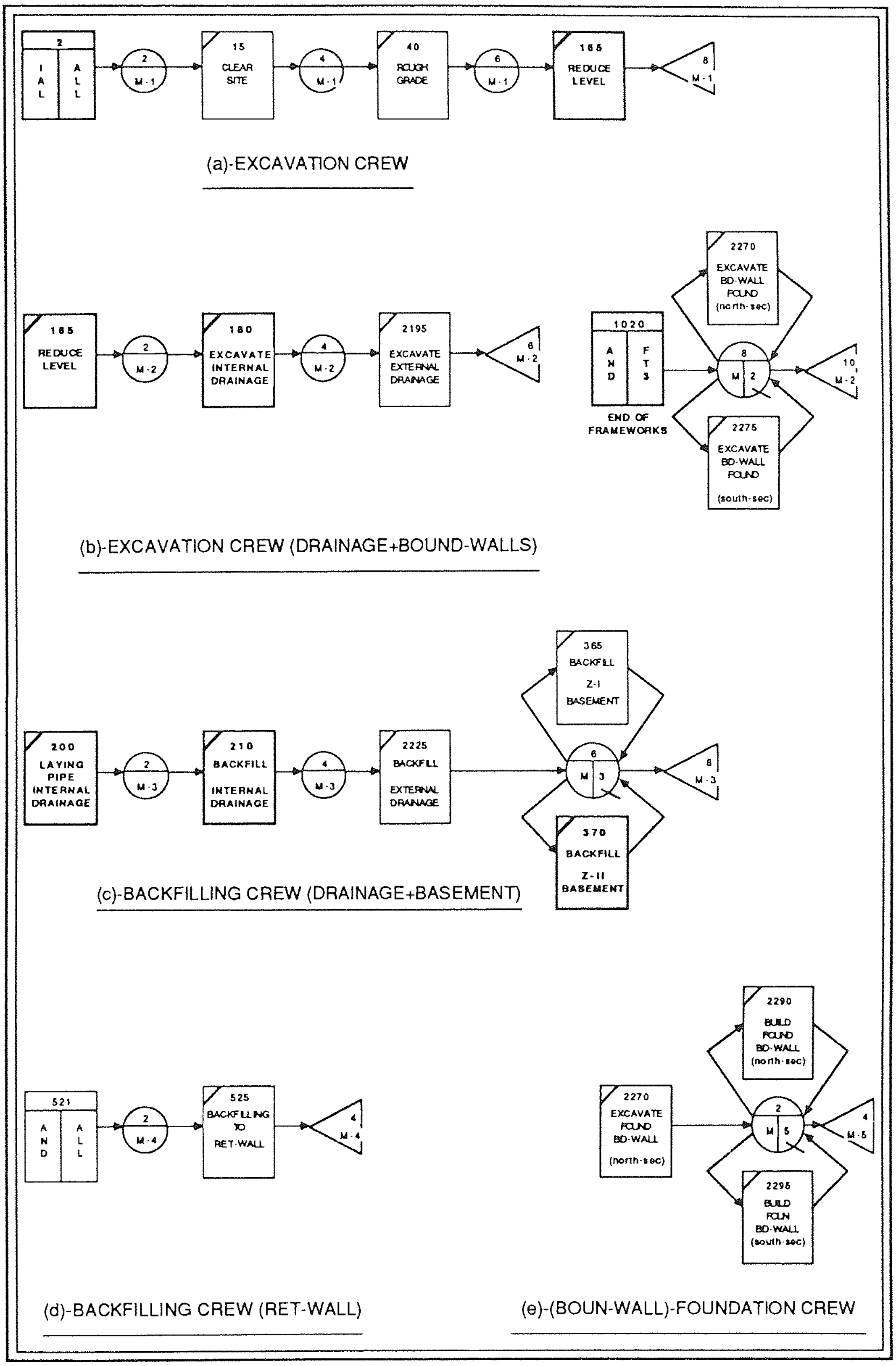

Figure (24)- Resource Networks Of Machinery Resource Category(1 to 5).

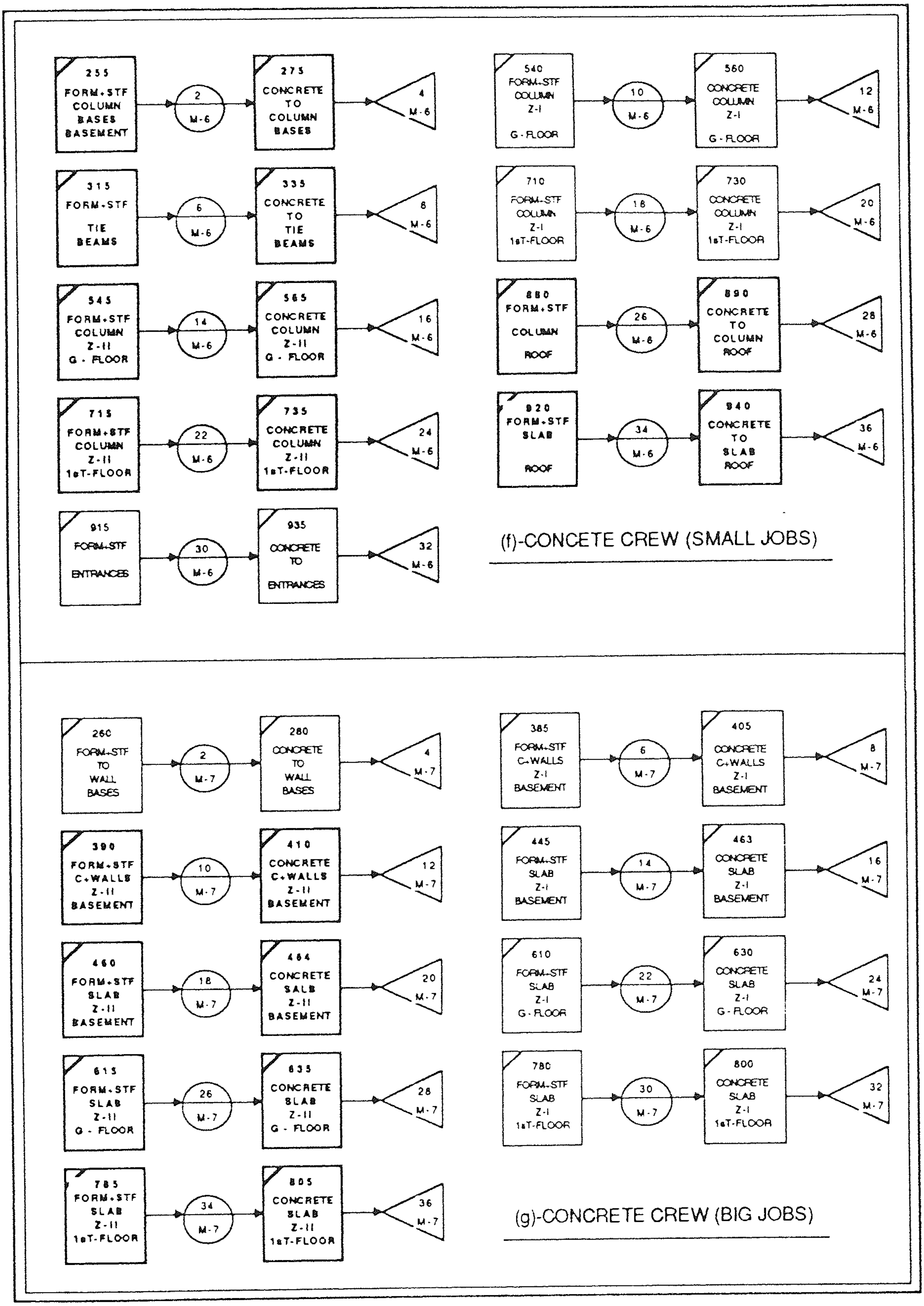

Figure (25)- Resource Networks For Machinery Category (6 and 7).

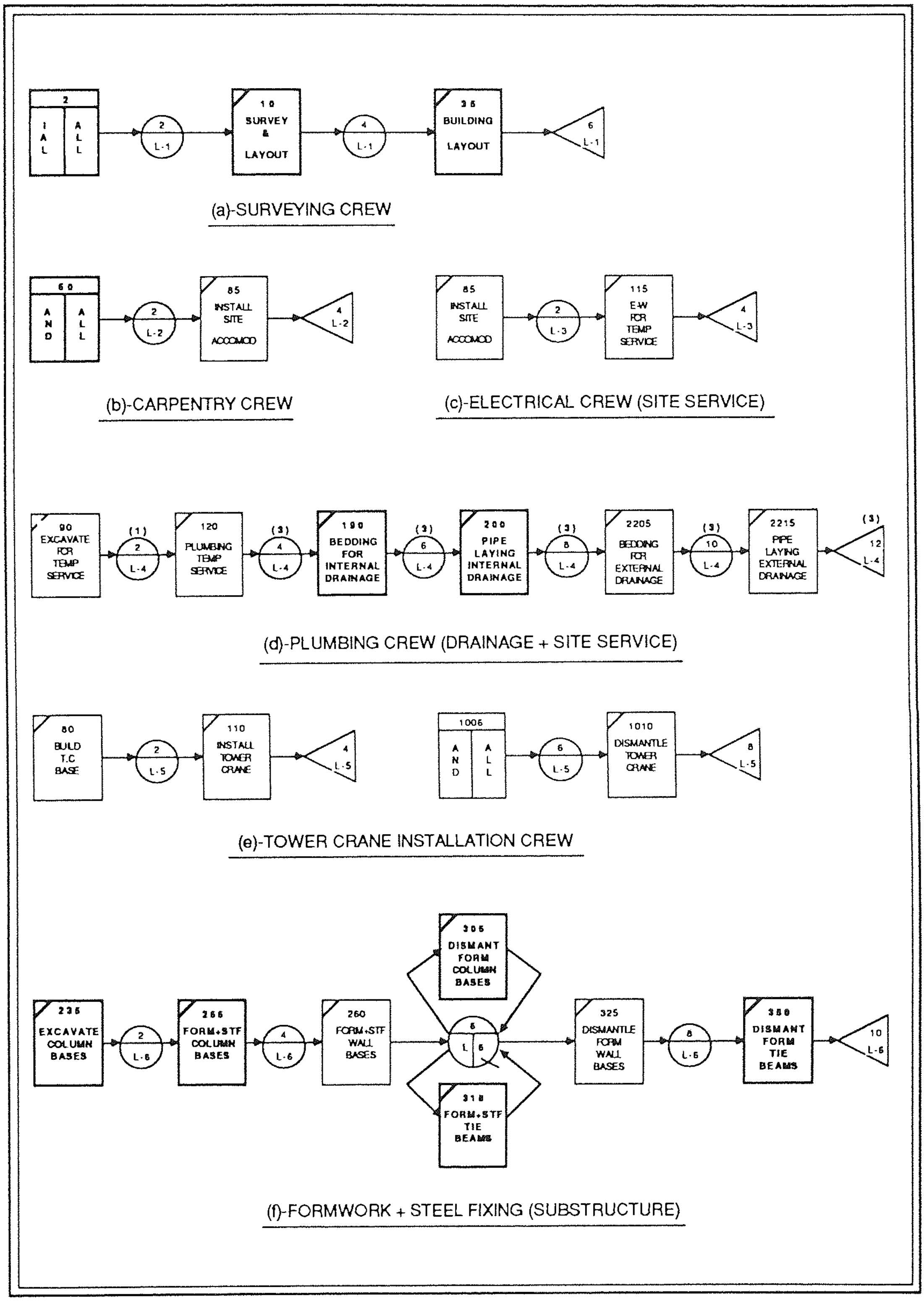

Figure (26)- Resource Networks for Labour Category (1 to 6) (first and second run).

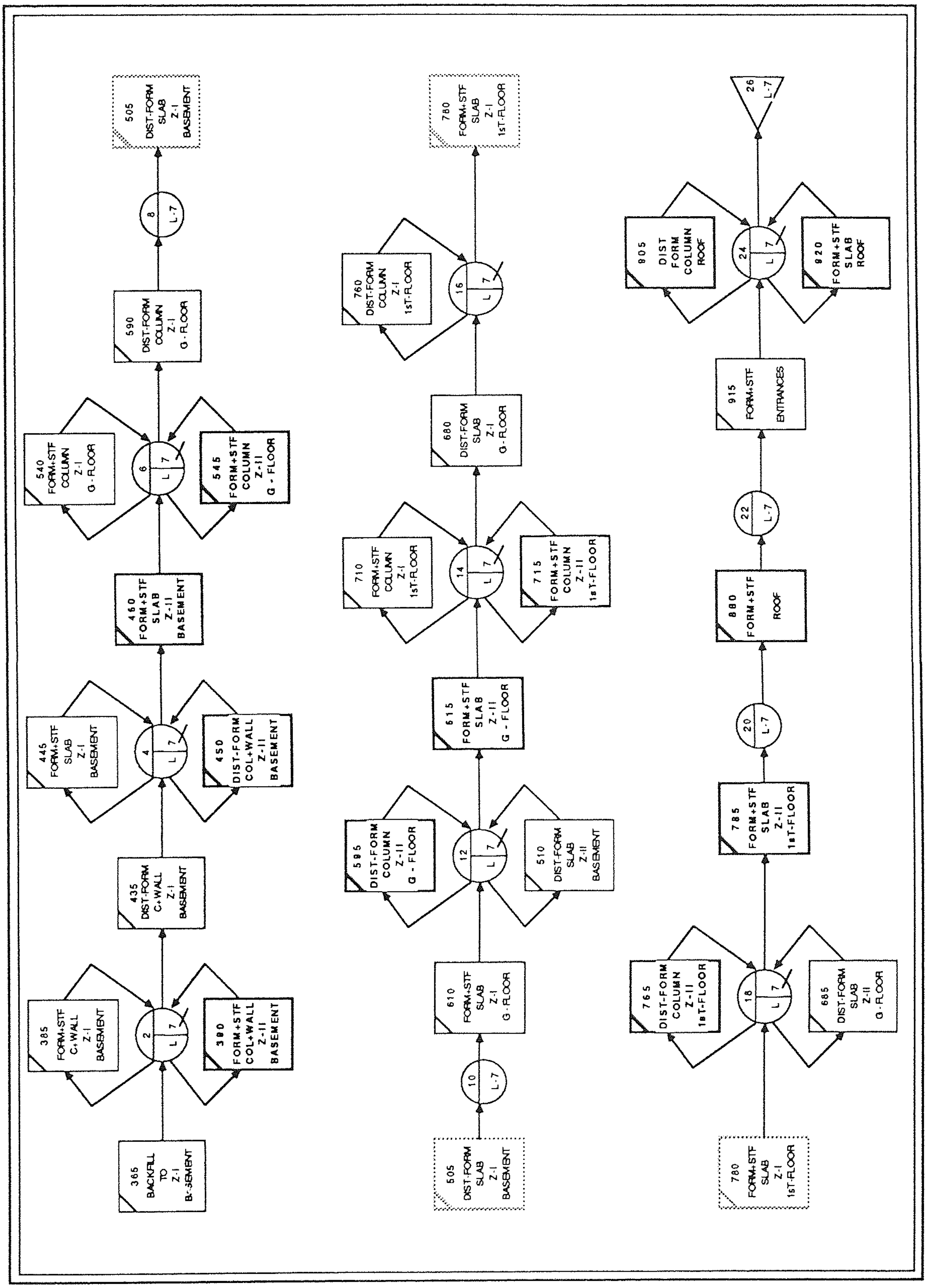

Figure (27)- Resource Network For Formwork Crew (first and second run).

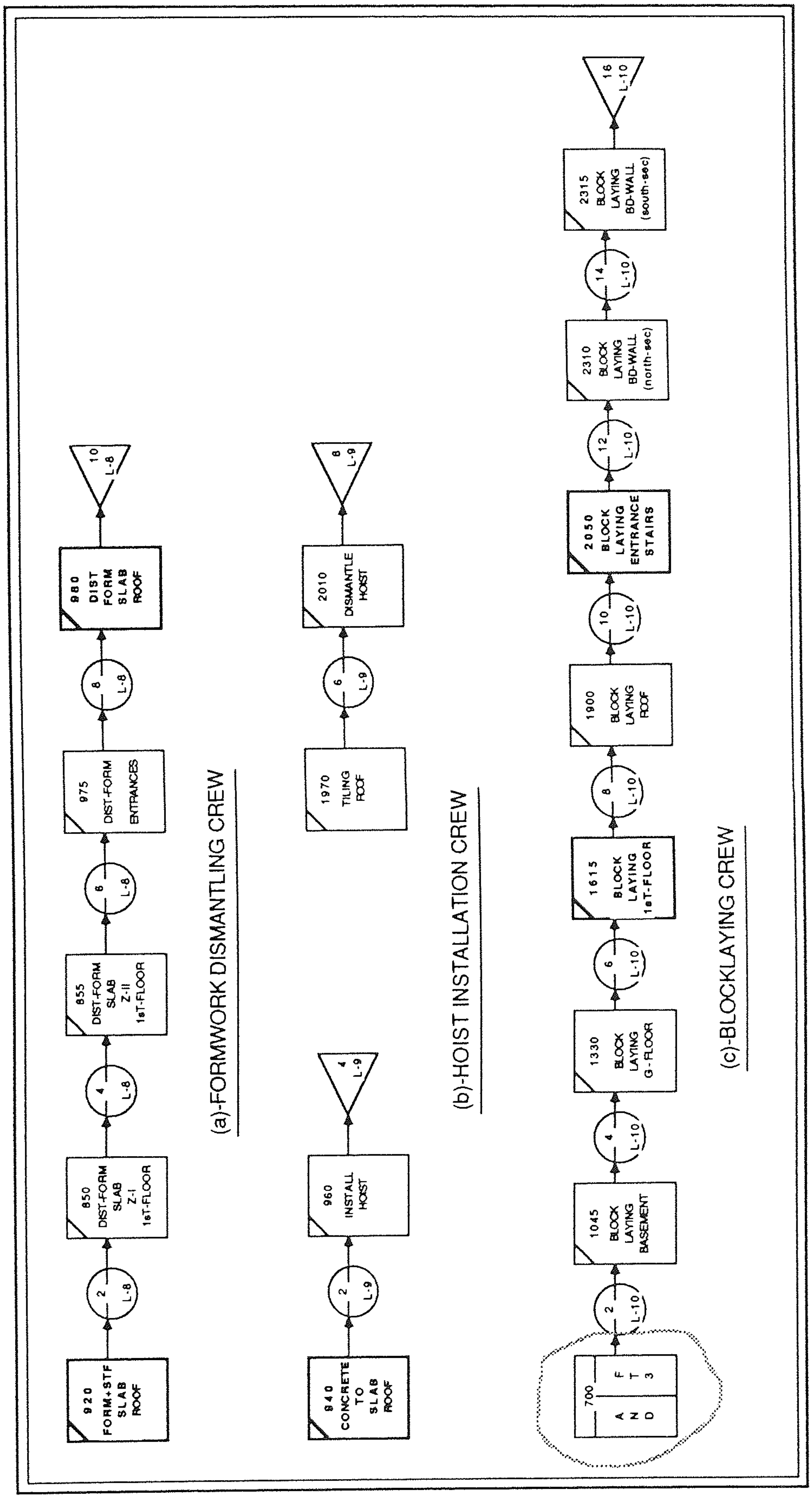

Figure (28)- Resource Networks Of Labour Category (8,9 and 10)(first run).

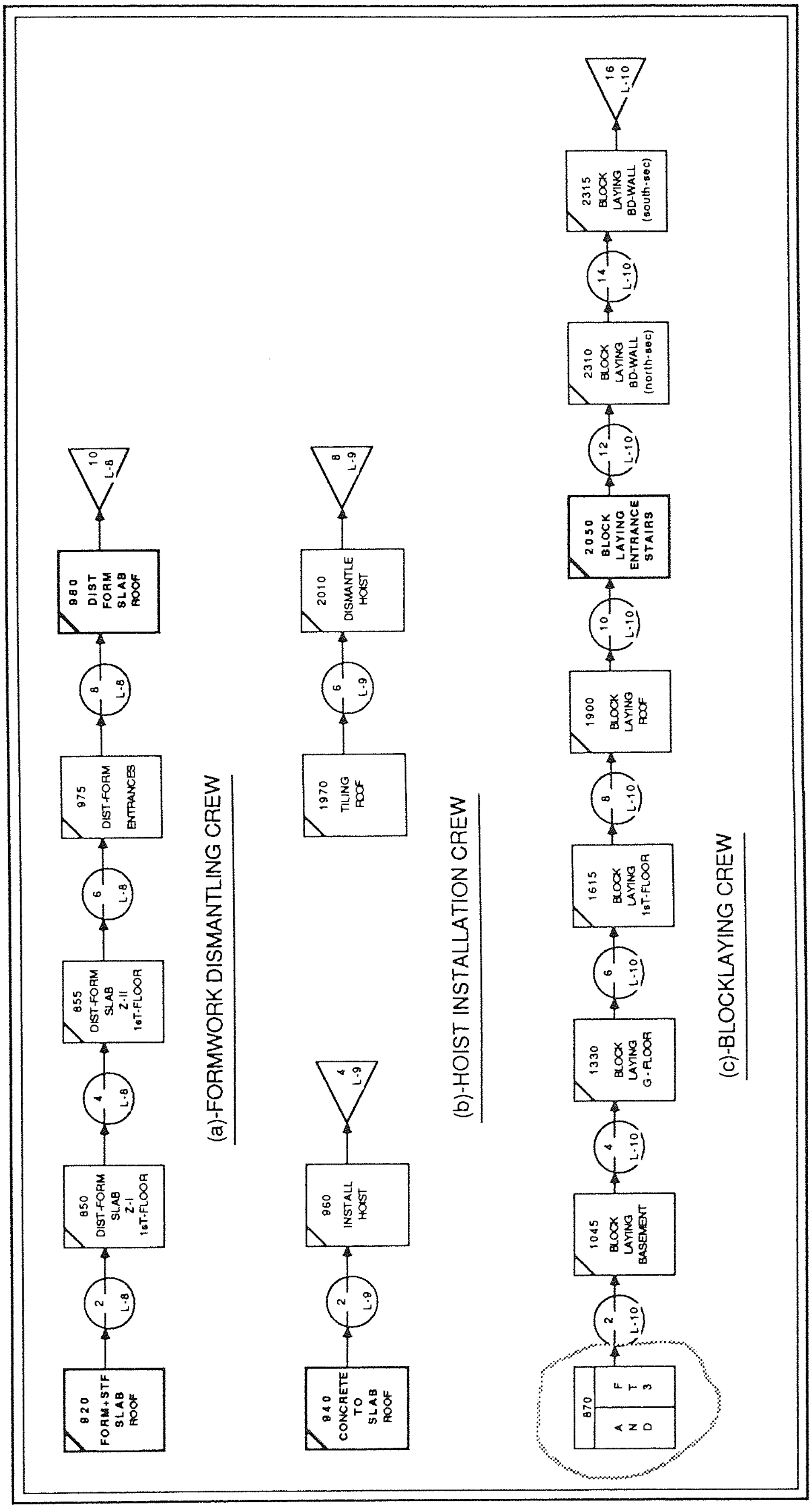

Figure (29)- Resource Networks Of Labour Category (8,9 and 10)(second run).

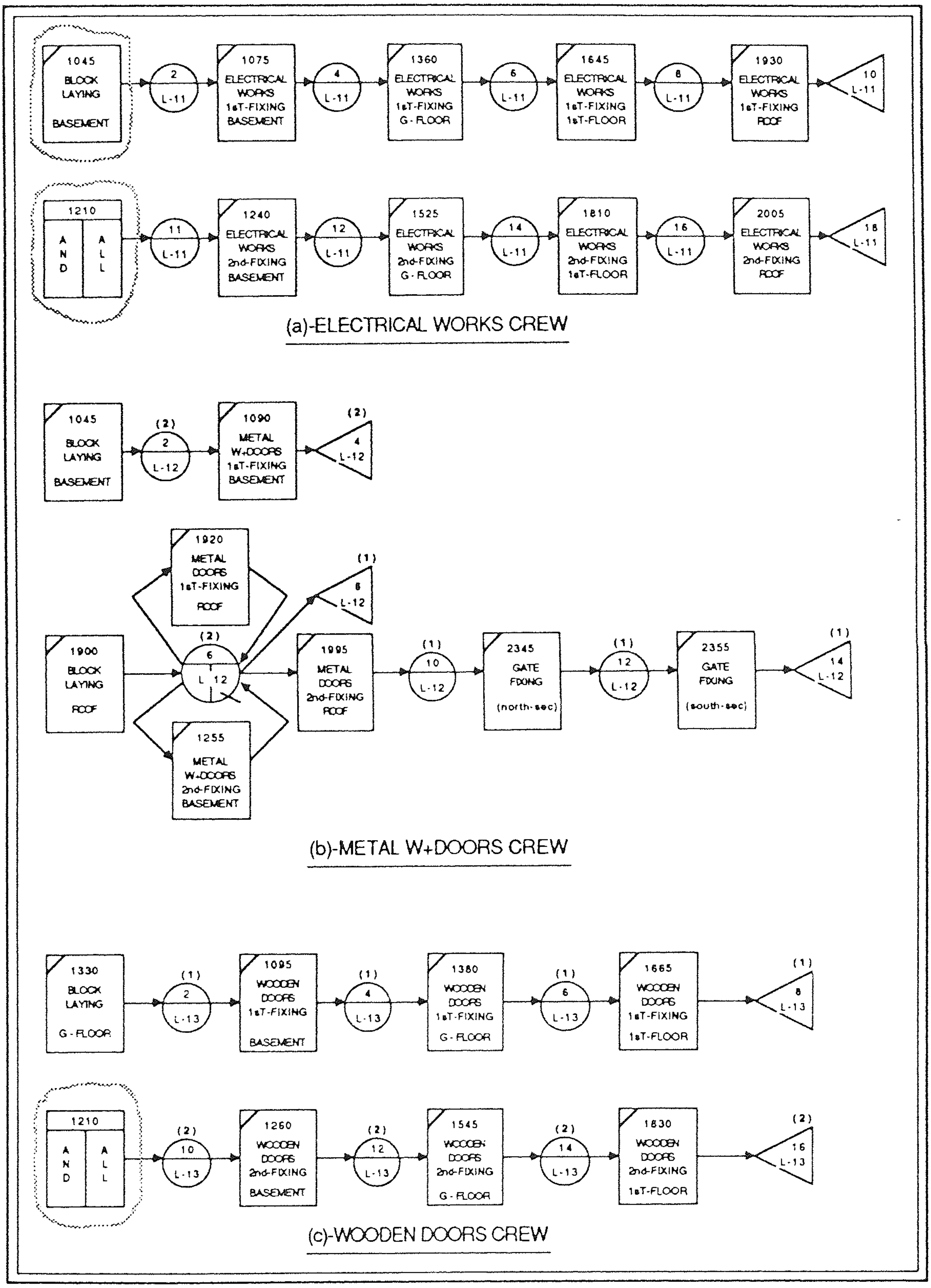

Figure (30)- Resource Networks Of Labour Category (11,12 and 13)(first run).

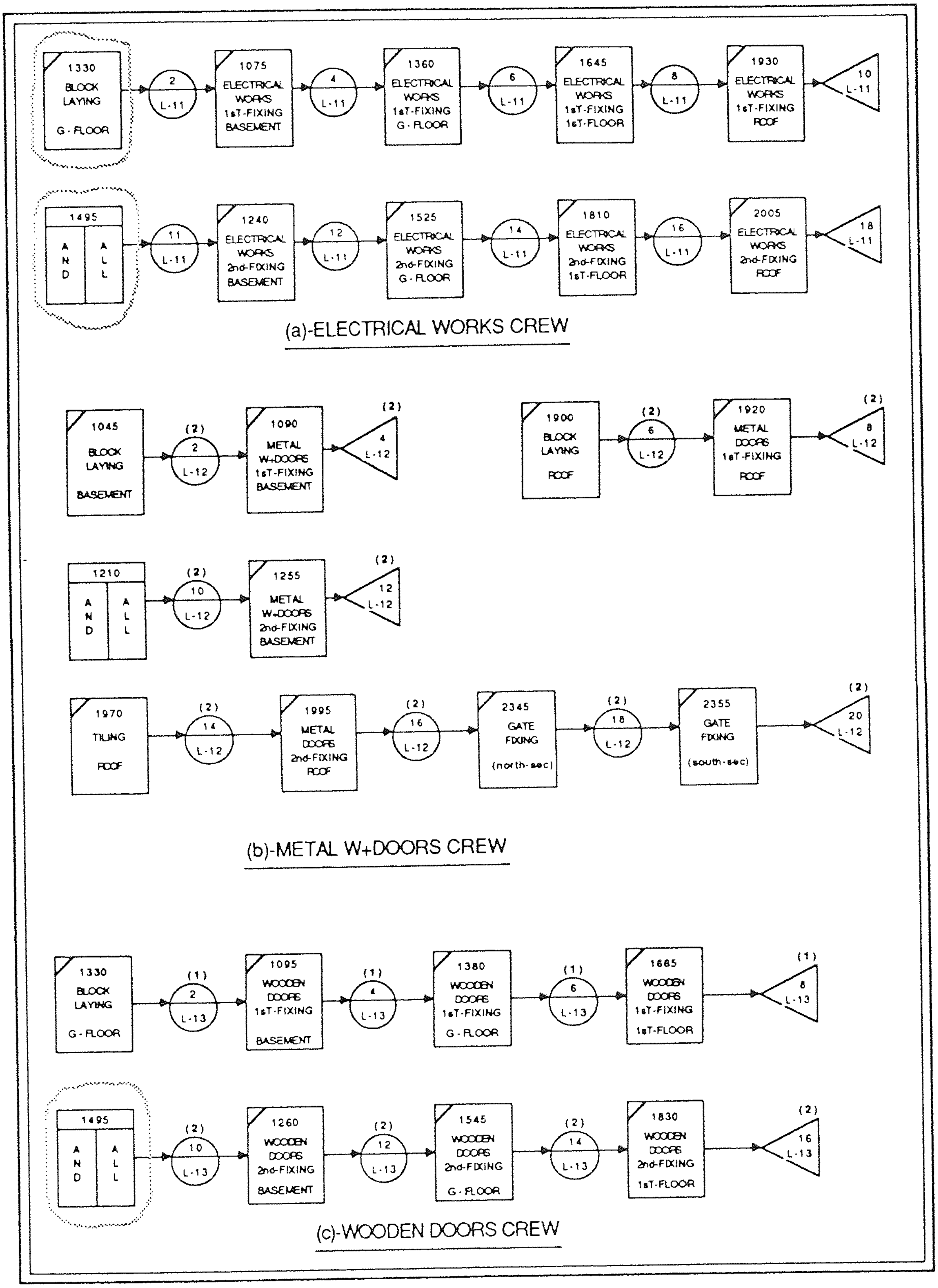

Figure (31)- Resource Networks Of Labour Category (11,12 and 13)(second run).

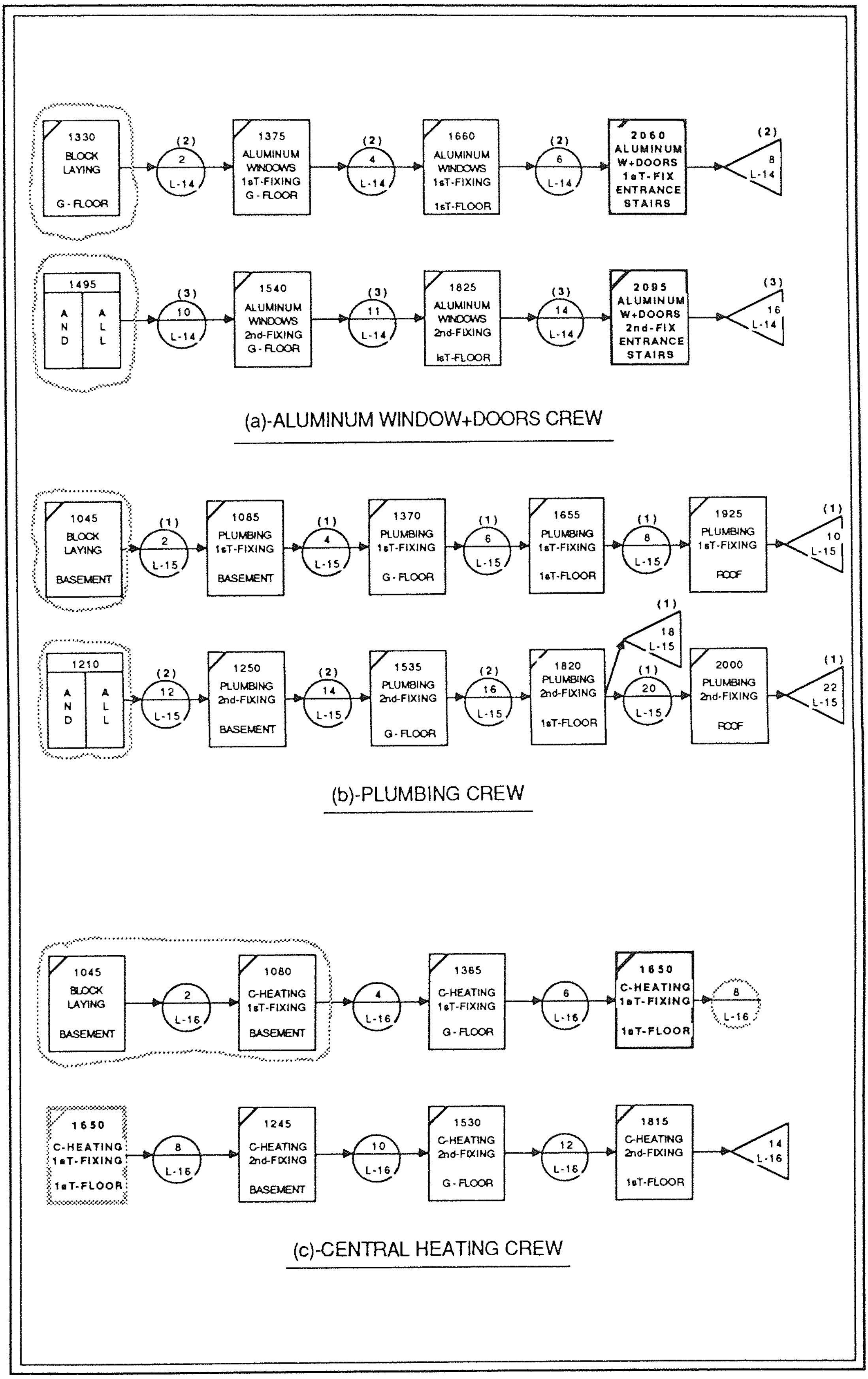

Figure (32)- Resource Networks Of Labour Category (14,15 and 16)(first run).

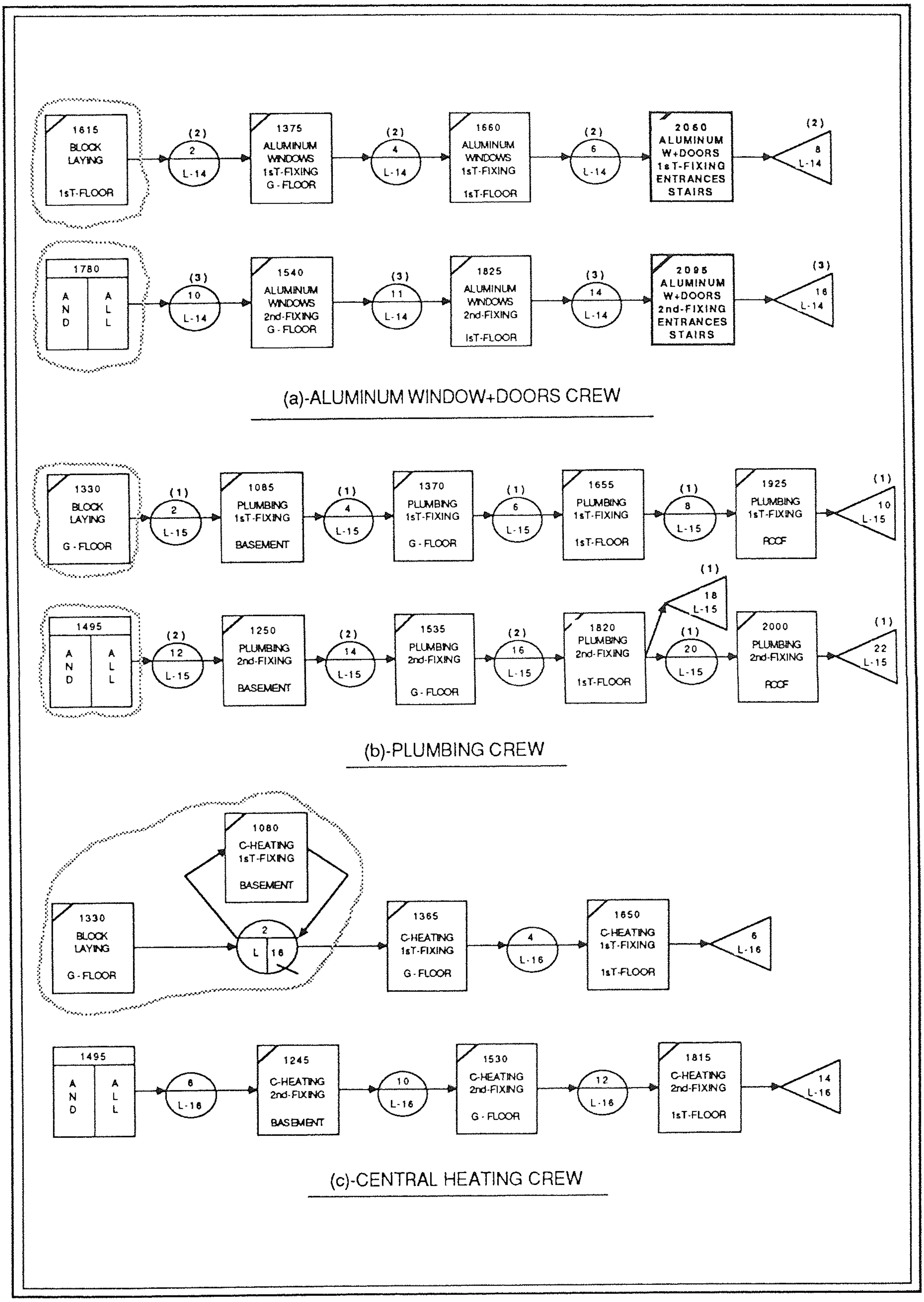

Figure (33)- Resource Networks Of Labour Category (14,15 and 16)(second run).

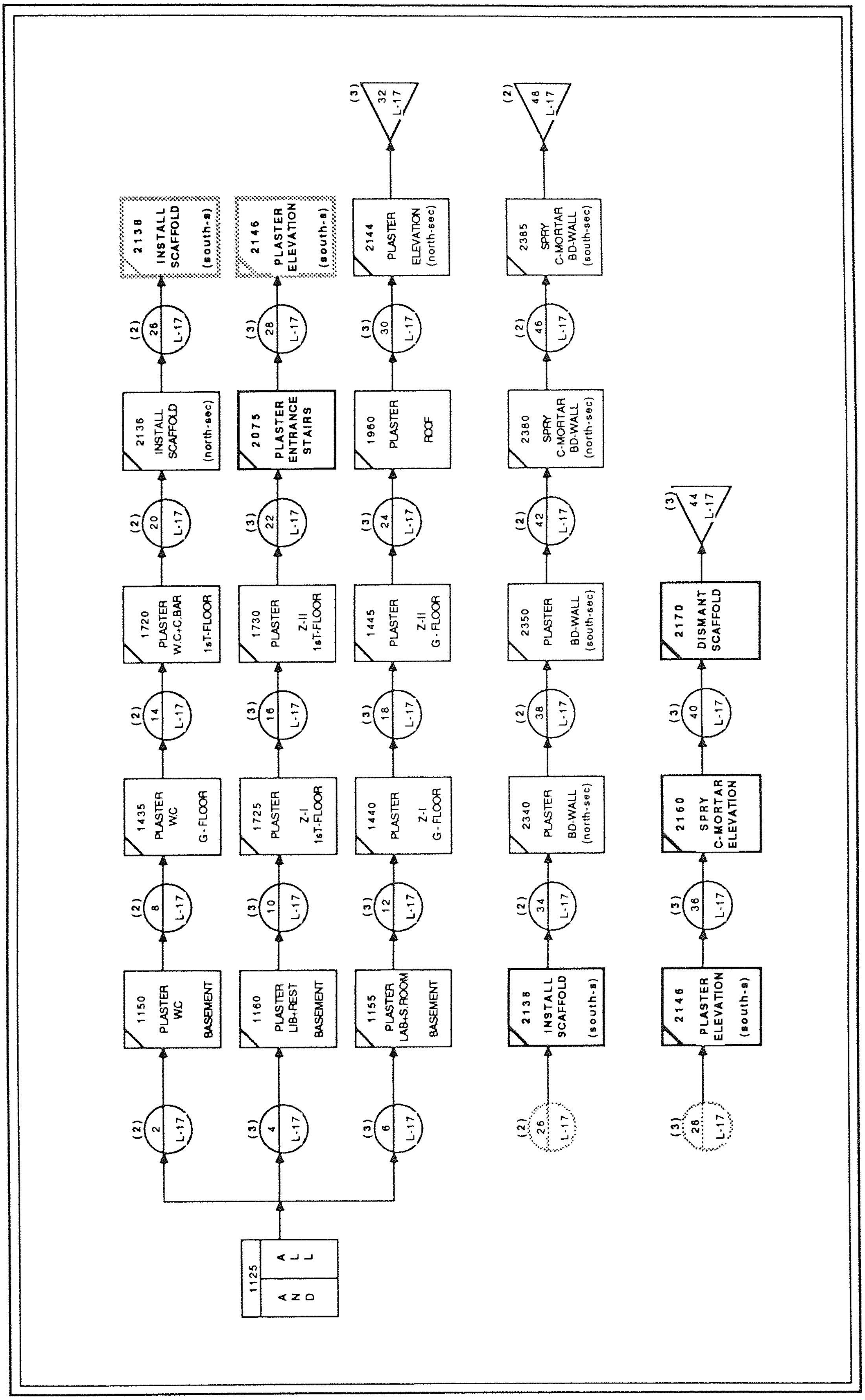

Figure (34)- Resource Network Of Plastering Crew (first run).

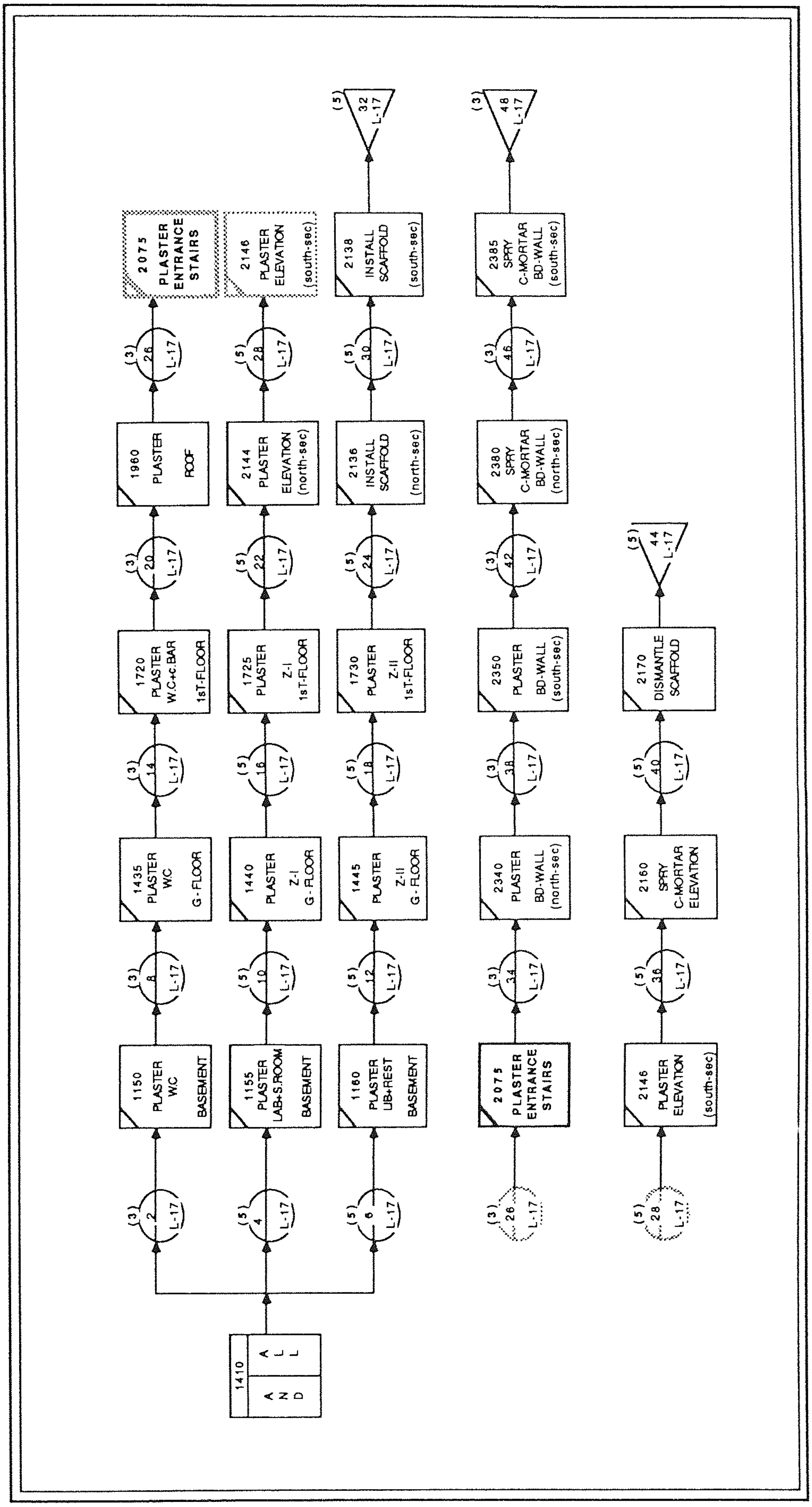

Figure (35)- Resource Network Of Plastering Crew (second run).

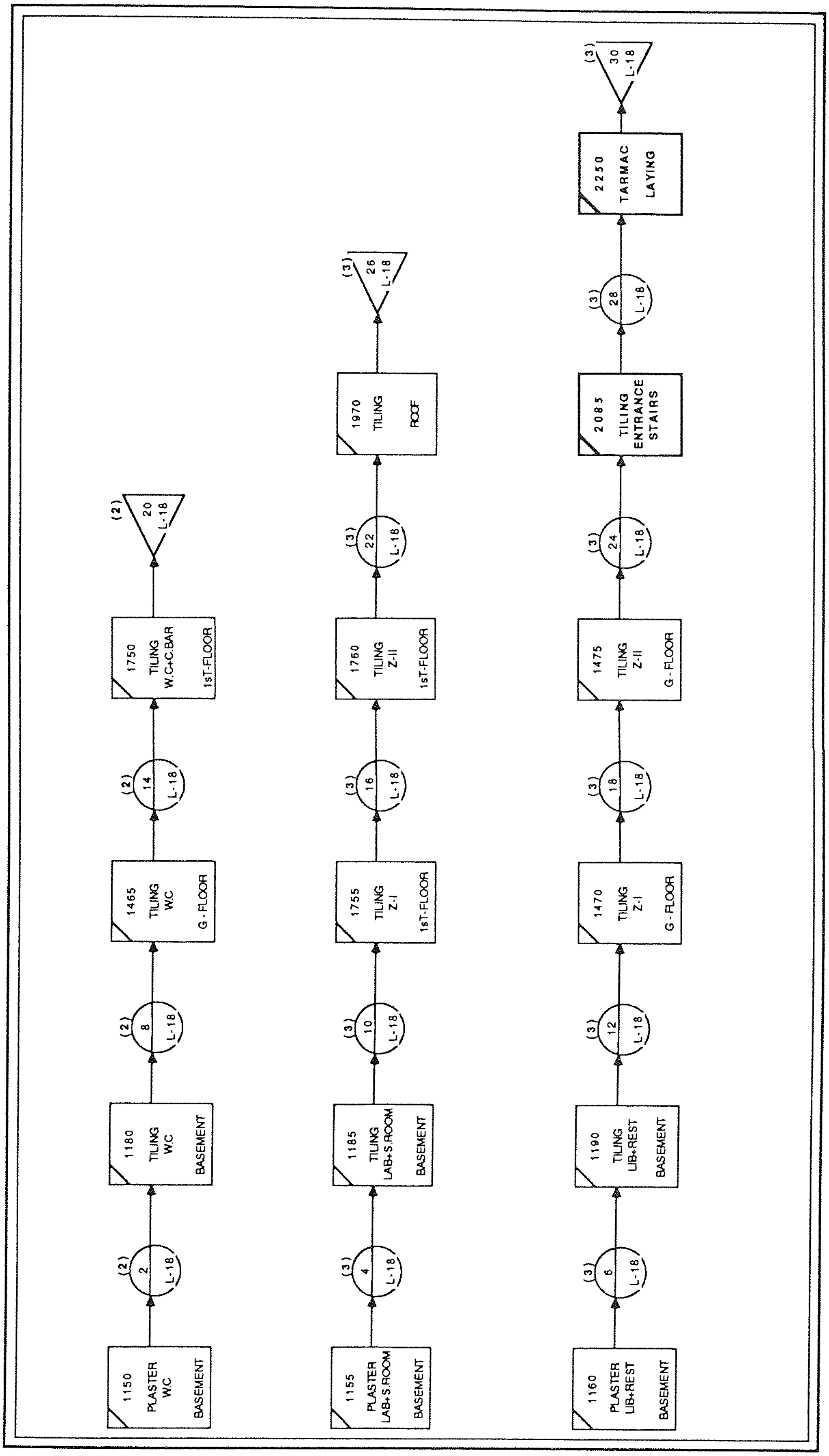

Figure (36)- Resource Network Of Tiling Crew (first run).

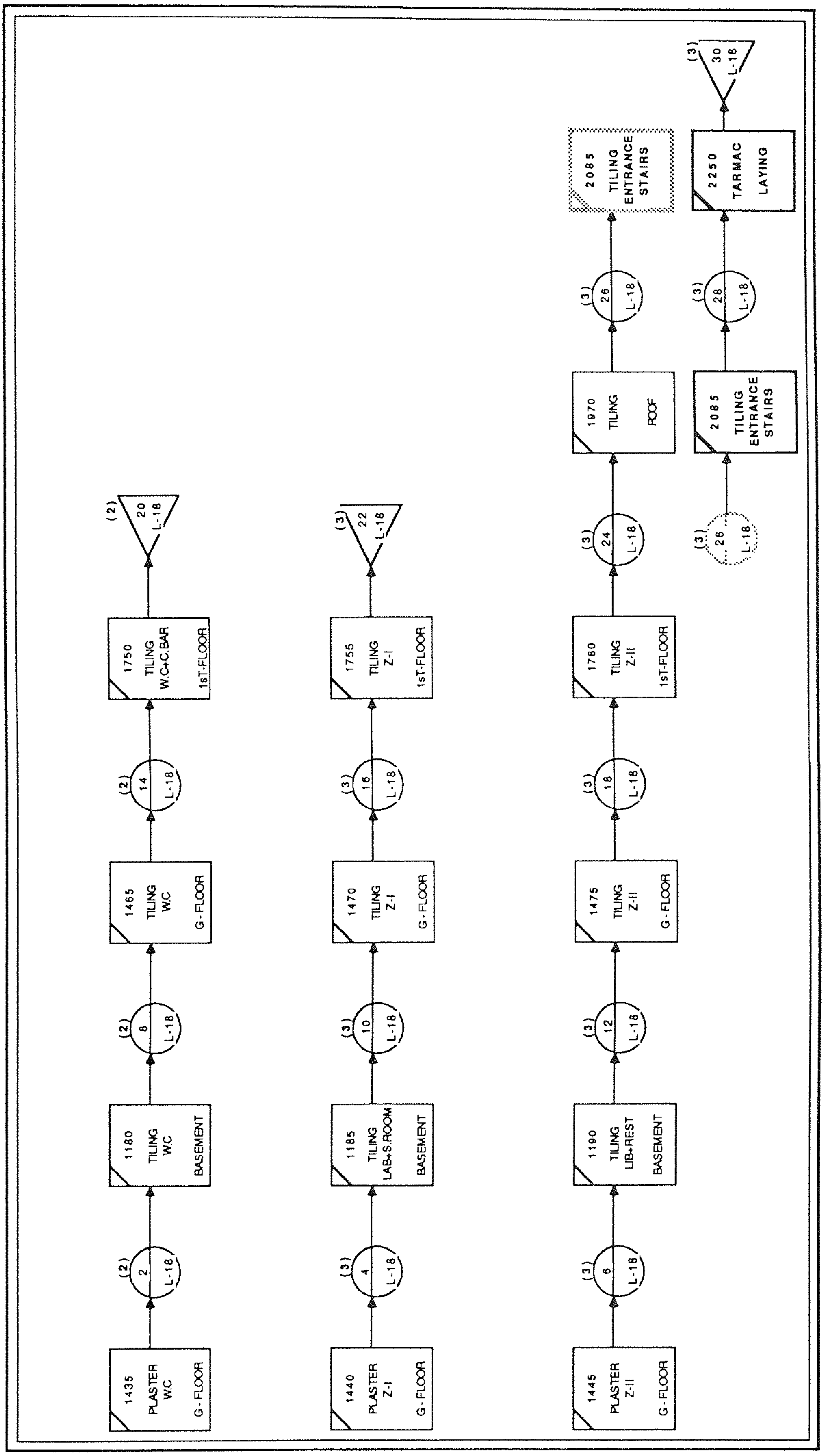

Figure (37)- Resource Network Of The Tiling Crew (second run).

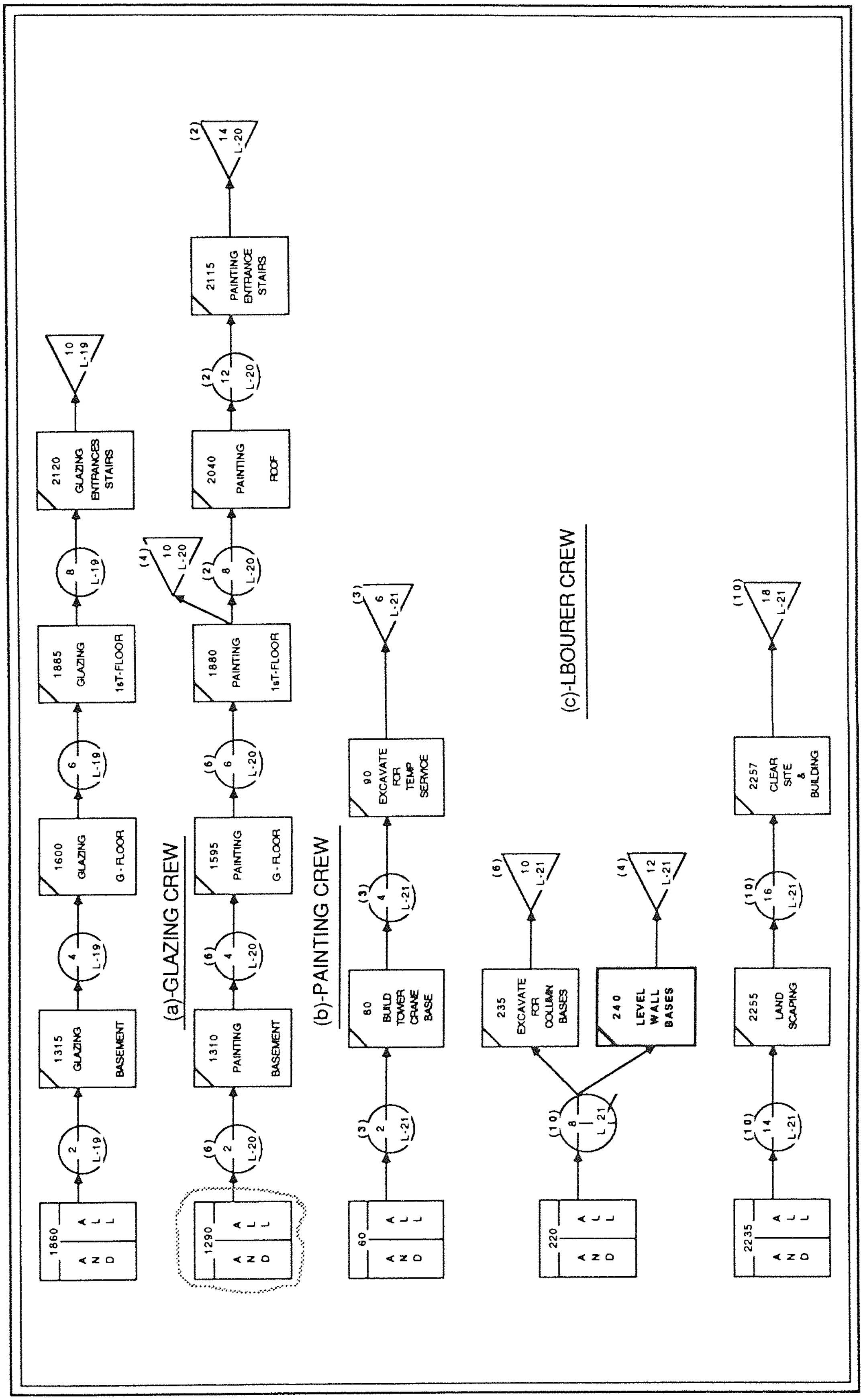

Figure (38)- Resource Network Of Labour Category (19,20 and 21)(first run).

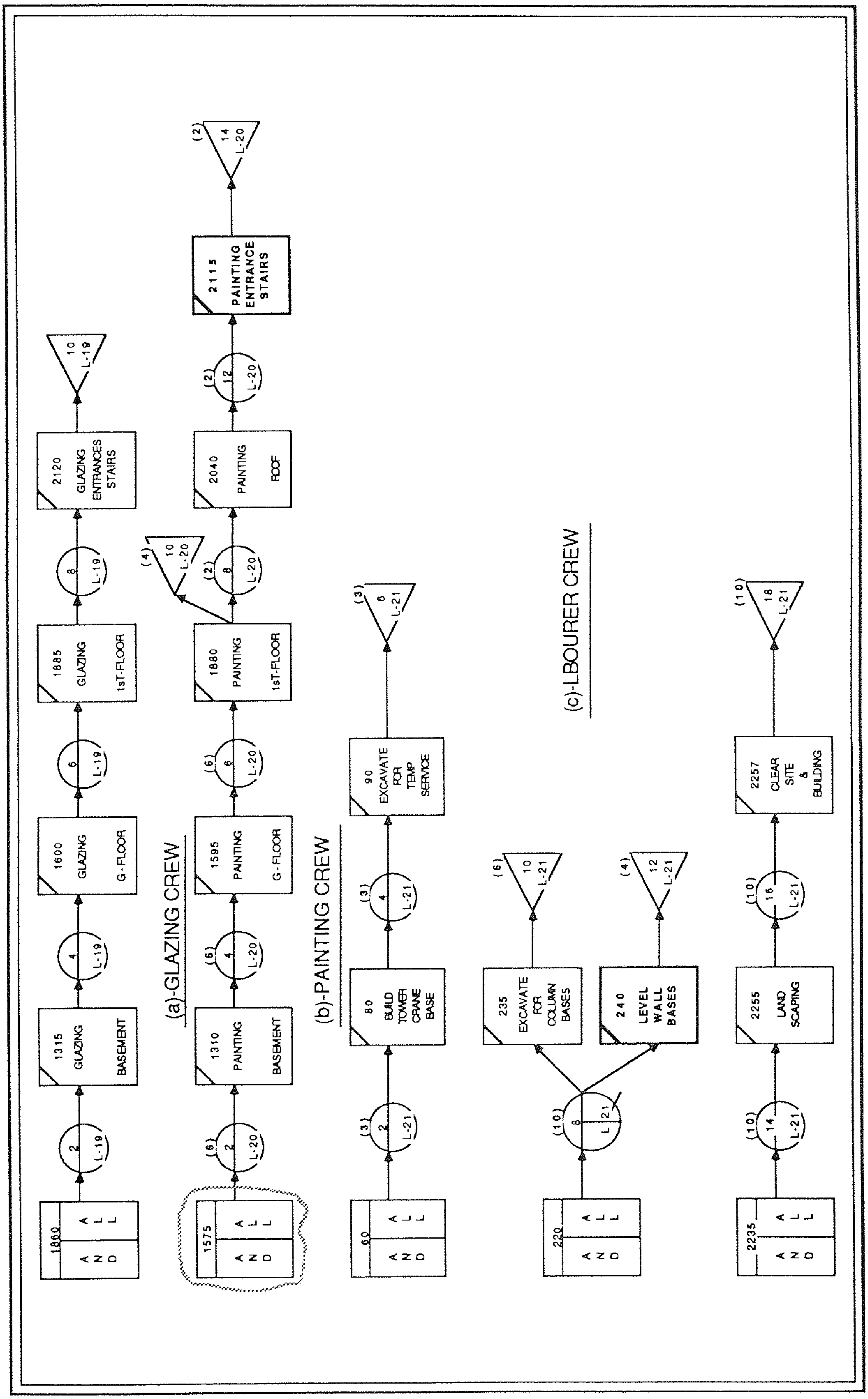

Figure (39)- Resource Networks Of Labour Category (19,20 and 21)(second run).

SEQ	NODE-NO C.P.M	NODE-NO VC	NODE DESCRIPTION	REALIZATION-TIME		COST	C - I
				ET	LT		
1	10	150	END OF SITE SET-UP	16	16	80400	•
2	20	220	END OF EXCAVATION (BUILDING+INT-D)	32	32	40800	•
3	35	530	END OF SUBSTRUCTURE-WORKS	99	99	47600	•
4	45	700	END OF FRAMEWORK (G - FLOOR)	131	131	213500	•
5	55	870	END OF FRAMEWORK (1sT-FLOOR)	163	163	211500	•
6	65	1020	END OF FRAMEWORKS IN THE PROJECT	175	197	37000	-
7	95	1320	END OF WORKS (BASEMENT)	161	218	313000	-
8	125	1605	END OF WORKS (G - FLOOR)	201	227	308500	-
9	155	1890	END OF WORK (1sT-FLOOR)	235	235	296000	•
10	200	2185	END OF WORK IN THE BUILDING	245	245	133500	•
11	240	2400	END OF EXTERNAL WORKS	235	245	132500	-
12	245	2410	END OF THE PROJECT	245	245	249000	•

Figure (40)- Milestones Time And Cost Targets As Defined By C.P.M. Analysis.

SEQ	NODE-NO	NODE DESCRIPTION	TIME CONST	COST CONSTRAINT	REALIZATION TIME				TCI	CCI	C-I
					MEAN	MIN	MAX	S.D			
1	150	END OF SITE SET-UP	16	80400	19.26	17.85	20.67	0.665	0.0	0.48	0.0
					19.54	17.77	21.27	0.745	0.0	0.44	0.0
2	220	END OF EXCAVATION (BUILDING+ INT-D)	32	40800	25.67	23.88	27.33	0.47	1.0	0.94	1.0
					23.64	21.79	25.18	0.771	1.0	0.94	1.0
3	530	END OF SUBSTRUCTURE WORKS	99	476000	98.92	94.83	103.05	1.7	0.52	1.0	0.0
					84.59	80.36	88.45	1.399	1.0	1.0	0.0
4	700	END OF FRAMEWORK (G - FLOOR)	131	213500	119.35	115.15	123.62	1.659	1.0	1.0	0.0
					100.43	95.90	104.90	1.448	1.0	1.0	0.0
5	870	END OF FRAMEWORK (1sT-FLOOR)	163	211500	144.71	140.52	149.08	1.626	1.0	1.0	0.34
					122.73	117.65	127.06	1.599	1.0	1.0	0.0
6	1020	END OF FRAMEWORKS IN THE PROJECT	197	37000	149.52	145.36	153.53	1.591	1.0	1.0	0.66
					124.73	119.65	129.06	1.598	1.0	1.0	1.0
7	1320	END OF WORKS (BASEMENT)	218	313000	231.55	223.47	240.44	3.445	0.0	1.0	0.0
					215.13	208.70	221.94	2.491	0.89	1.0	0.0
8	1605	END OF WORKS (G - FLOOR)	227	308500	232.48	223.94	242.52	3.367	0.03	1.0	0.0
					222.49	216.50	230.27	2.358	0.98	1.0	0.0
9	1890	END OF WORKS (1sT-FLOOR)	235	296000	238.86	232.47	247.18	3.038	0.08	0.0	0.0
					232.58	226.41	240.70	2.487	0.87	0.31	0.0
10	2185	END OF WORKS IN THE BUILDING	245	133500	251.86	244.80	259.13	3.018	0.01	0.0	0.0
					240.09	233.65	247.81	2.473	0.97	0.83	1.0
11	2400	END OF EXTERNAL WORKS	245	132500	265.33	257.76	272.97	3.054	0.0	0.0	1.0
					232.14	225.40	238.03	2.543	1.0	0.0	0.0
12	2410	END OF THE PROJECT	245	2490000	265.33	257.76	272.97	3.054	0.0	1.0	1.0
					240.09	233.65	247.81	2.473	0.97	1.0	1.0

Figure (41)- Milestones Parameters As Defined By The First And Second Simulation run.

SEQ	NODE NO	NODE DESCRIPTION	COST/DAY	TOTAL COST			
				MEAN	MIN	MAX	S.D
1	BT-8	SITE OVERHEAD COST (SITE SET-UP)	£ 200	3651.53	33295.57	3933.25	133.06
				3707.531	3354.95	4053.48	148.933
2	BT-140	TOWER CRANE COST	£ 500	66107.27	64410.21	68141.09	744.65
				53722.25	51622.61	55659.99	792.767
3	BT-160	SITE OVERHEAD COST (TO THE END)	£ 1000	246073.98	238344.01	253756.38	3054.62
				220553.06	213478.39	226787.17	2419.34
4	BT-990	HOIST COST	£ 200	18430.23	17398.75	19788.86	483.26
				17702.09	16974.11	18587.96	282.73

Figure (42)- Cost/Day And Statistics On Total Overhead And Operating Cost (first and second run).

```
MILESTONES & TERMINAL NODE REPORT.
**********************************

NODE'S NUMBER= 2                NODE'S TYPE= 28              C-INDEX= 1
STARTING TIME= 1                INITIAL COST= 10000
          ------------------------------------

NODE'S NUMBER= 60               NODE'S TYPE= 12              C-INDEX= 0
          ------------------------------------

NODE'S NUMBER= 150              NODE'S TYPE= 18              C-INDEX= 0
TIME CONSTRAINT= 16             PROB.OF.ACHIEVING IT= 0
COST CONSTRAINT= 30400          PROB.OF.ACHIEVING IT= .48
          ------------------------------------

NODE'S NUMBER= 220              NODE'S TYPE= 18              C-INDEX= 1
TIME CONSTRAINT= 32             PROB.OF.ACHIEVING IT= 1
COST CONSTRAINT= 40800          PROB.OF.ACHIEVING IT= .94
          ------------------------------------

NODE'S NUMBER= 330              NODE'S TYPE= 12              C-INDEX= 1
          ------------------------------------

NODE'S NUMBER= 521              NODE'S TYPE= 12              C-INDEX= 0
          ------------------------------------

NODE'S NUMBER= 530              NODE'S TYPE= 18              C-INDEX= 0
TIME CONSTRAINT= 99             PROB.OF.ACHIEVING IT= .52
COST CONSTRAINT= 476000         PROB.OF.ACHIEVING IT= 1
          ------------------------------------

NODE'S NUMBER= 700              NODE'S TYPE= 18              C-INDEX= 0
TIME CONSTRAINT= 131            PROB.OF.ACHIEVING IT= 1
COST CONSTRAINT= 213500         PROB.OF.ACHIEVING IT= 1
          ------------------------------------

NODE'S NUMBER= 870              NODE'S TYPE= 18              C-INDEX= .74
TIME CONSTRAINT= 163            PROB.OF.ACHIEVING IT= 1
COST CONSTRAINT= 211500         PROB.OF.ACHIEVING IT= 1
          ------------------------------------

NODE'S NUMBER= 1006             NODE'S TYPE= 12              C-INDEX= 0
          ------------------------------------

NODE'S NUMBER= 1020             NODE'S TYPE= 18              C-INDEX= .66
TIME CONSTRAINT= 197            PROB.OF.ACHIEVING IT= 1
COST CONSTRAINT= 37000          PROB.OF.ACHIEVING IT= 1
          ------------------------------------

NODE'S NUMBER= 1125             NODE'S TYPE= 12              C-INDEX= 0
          ------------------------------------

NODE'S NUMBER= 1210             NODE'S TYPE= 12              C-INDEX= 0
          ------------------------------------

NODE'S NUMBER= 1290             NODE'S TYPE= 12              C-INDEX= 0
          ------------------------------------
```

Figure (43)- Summary Report On Milestones And TERMINAL Node (first run).

```
NODE'S NUMBER= 1320              NODE'S TYPE= 18              C-INDEX= 0
TIME CONSTRAINT= 218             PROB.OF.ACHIEVING IT= 0
COST CONSTRAINT= 313000          PROB.OF.ACHIEVING IT= 1
                     ----------------------------------

NODE'S NUMBER= 1410              NODE'S TYPE= 12              C-INDEX= 0
                     ----------------------------------

NODE'S NUMBER= 1495              NODE'S TYPE= 12              C-INDEX= 0
                     ----------------------------------

NODE'S NUMBER= 1575              NODE'S TYPE= 12              C-INDEX= 0
                     ----------------------------------

NODE'S NUMBER= 1605              NODE'S TYPE= 18              C-INDEX= 0
TIME CONSTRAINT= 227             PROB.OF.ACHIEVING IT= .03
COST CONSTRAINT= 308500          PROB.OF.ACHIEVING IT= 1
                     ----------------------------------

NODE'S NUMBER= 1695              NODE'S TYPE= 12              C-INDEX= .34
                     ----------------------------------

NODE'S NUMBER= 1780              NODE'S TYPE= 12              C-INDEX= 0
                     ----------------------------------

NODE'S NUMBER= 1860              NODE'S TYPE= 12              C-INDEX= 0
                     ----------------------------------

NODE'S NUMBER= 1890              NODE'S TYPE= 18              C-INDEX= 0
TIME CONSTRAINT= 235             PROB.OF.ACHIEVING IT= .08
COST CONSTRAINT= 296000          PROB.OF.ACHIEVING IT= 0
                     ----------------------------------

NODE'S NUMBER= 1950              NODE'S TYPE= 12              C-INDEX= 0
                     ----------------------------------

NODE'S NUMBER= 2030              NODE'S TYPE= 12              C-INDEX= 0
                     ----------------------------------

NODE'S NUMBER= 2110              NODE'S TYPE= 12              C-INDEX= .57
                     ----------------------------------

NODE'S NUMBER= 2155              NODE'S TYPE= 12              C-INDEX= 1
                     ----------------------------------

NODE'S NUMBER= 2185              NODE'S TYPE= 18              C-INDEX= 0
TIME CONSTRAINT= 245             PROB.OF.ACHIEVING IT= .01
COST CONSTRAINT= 177500          PROB.OF.ACHIEVING IT= 0
                     ----------------------------------

NODE'S NUMBER= 2235              NODE'S TYPE= 12              C-INDEX= 1
                     ----------------------------------

NODE'S NUMBER= 2400              NODE'S TYPE= 18              C-INDEX= 1
TIME CONSTRAINT= 245             PROB.OF.ACHIEVING IT= 0
COST CONSTRAINT= 122500          PROB.OF.ACHIEVING IT= 1
                     ----------------------------------
```

Figure (43)- Continued.

```
HARD COPY OF TERM NODE'S PARA DIST.
***********************************


       0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
   MIN-I----I----I----I----I----I----I----I----I----I----I----I
257.76-I.....................................................  0.010
259.03-I**...................................................0.040
260.30-I*....................................................0.020
261.57-I***..................................................  0.070
262.83-I*******..............................................0.140
264.10-I******...............................................  0.140
265.37-I********.............................................0.160
266.64-I********.............................................  0.170
267.90-I****.................................................0.090
269.17-I*****................................................0.100
270.44-I.....................................................  0.020
271.70-I*....................................................  0.030
272.97-I.....................................................0.010
   MAX-I----I----I----I----I----I----I----I----I----I----I----I
   TN-TYPE   = 26           MIN   = 257.76        MODE VALUE= 266.64
   NO.OF.OBS= 100           MAX   = 272.97        MODE PROB =    0.170
   TIME-CONS= 245           MEAN  = 265.33        PEAR SKEW =    1.30
   TCI-INDEX=0.000          S.D   =   3.054       PEAR-COFF =    0.427
                            C.O.V=   0.012

                    (a)-PDF OF COPMLETION TIME.
                    ---------------------------
```

```
       0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
   MIN-I----I----I----I----I----I----I----I----I----I----I----I
                                                              .0.000
257.13-I.....................................................  0.010
258.40-I.....................................................  0.050
259.67-I**...................................................  0.070
260.93-I***..................................................0.140
262.20-I*******..............................................0.280
263.47-I*************........................................0.420
264.73-I*********************................................0.580
266.00-I*****************************........................  0.750
267.27-I*************************************................0.840
268.54-I*******************************************..........0.940
269.90-I*********************************************........0.960
271.07-I**********************************************.....  0.990
272.34-I***********************************************......1.000
273.61-I*****************************************************I----I
   MAX-I----I----I----I----I----I----I----I----I----I----I----I
   TN-TYPE   = 26           MIN   = 257.76        MODE VALUE= 266.64
   NO.OF.OBS= 100           MAX   = 272.97        MODE PROB =    0.170
   TIME-CONS= 245           MEAN  = 265.33        PEAR SKEW =    1.30
   TCI-INDEX=0.000          S.D   =   3.054       PEAR-COFF =    0.427
                            C.O.V=   0.012

                    (b)-CDF OF COMPLETION TIME.
                    ---------------------------
```

Figure (44)- (PDF) And (CDF) Of Project Completion Time (first run).

```
             0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
         MIN-I----I----I----I----I----I----I----I----I----I----I----I----I
2410055.50-I.................................................... 0.010
2412695.50-I*...................................................0.020
2415335.00-I**..................................................0.050
2417975.00-I**..................................................0.050
2420614.50-I*****............................................... 0.110
2423254.50-I*****............................................... 0.110
2425894.00-I***********.........................................0.220
2428534.00-I********............................................0.160
2431173.50-I******..............................................0.120
2433813.50-I****................................................0.090
2436453.00-I*................................................... 0.030
2439093.00-I.................................................... 0.020
2441732.50-I....................................................0.010
         MAX-I----I----I----I----I----I----I----I----I----I----I----I----I
         TN-TYPE   = 26          MIN  = 2410055.50      MODE VALUE= 2425894.00
         NO.OF.OBS= 100          MAX  = 2441732.20      MODE PROB =      0.220
         COST-CONS= 2490000      MEAN = 2426184.50      PEAR SKEW =     290.50
         CCI-INDEX=1.000         S.D  =    6270.694     PEAR-COFF =      0.046
                                 C.O.V=       0.003

                                 (c)-PDF OF NET COST.
                                 --------------------
```

```
             0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
         MIN-I----I----I----I----I----I----I----I----I----I----I----I----I
                                                                .0.000
2408735.80-I.................................................... 0.010
2411375.50-I.................................................... 0.030
2414015.20-I*...................................................0.080
2416655.00-I****................................................ 0.130
2419294.80-I******..............................................0.240
2421934.50-I************........................................ 0.350
2424574.20-I*****************................................... 0.570
2427214.00-I***************************......................... 0.730
2429853.80-I*************************************............... 0.850
2432493.50-I********************************************........0.940
2435133.20-I**********************************************..... 0.970
2437773.00-I***********************************************.... 0.990
2440412.80-I************************************************....1.000
2443052.00-I*************************************************************
         MAX-I----I----I----I----I----I----I----I----I----I----I----I----I
         TN-TYPE   = 26          MIN  = 2410055.50      MODE VALUE= 2425894.00
         NO.OF.OBS= 100          MAX  = 2441732.20      MODE PROB =      0.220
         COST-CONS= 2490000      MEAN = 2426184.50      PEAR SKEW =     290.50
         CCI-INDEX=1.000         S.D  =    6270.694     PEAR-COFF =      0.046
                                 C.O.V=       0.003

                                 (d)-CDF OF NET COST.
                                 --------------------
```

Figure (45)- (PDF) And (CDF) Of Project Net Cost (first run).

```
           0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
       MIN-I----I----I----I----I----I----I----I----I----I----I----I
248561.41-I.................................................. 0.010
252714.06-I*.................................................0.020
256866.75-I*.................................................0.020
261019.41-I**................................................ 0.050
265172.09-I******............................................ 0.130
269324.78-I*******...........................................0.140
273477.47-I*******........................................... 0.160
277630.16-I******............................................0.120
281782.34-I******............................................0.120
285935.53-I****.............................................. 0.090
290088.22-I***............................................... 0.080
294240.91-I**................................................ 0.050
298393.53-I..................................................0.010
       MAX-I----I----I----I----I----I----I----I----I----I----I----I
       TN-TYPE  = 26        MIN  =  248561.41      MODE VALUE=  273477.47
       NO.OF.OBS= 100       MAX  =  298393.47      MODE PROB =       0.160
                            MEAN =  275560.31      PEAR SKEW =     2082.84
                            S.D  =   10481.160     PEAR-COFF =       0.199
                            C.O.V=       0.038

              e)-PDF OF COST OF IDLE TIME OF RESOURCES.
              -----------------------------------------
```

```
           0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
       MIN-I----I----I----I----I----I----I----I----I----I----I----I
                                                             0.000
248485.06-I.................................................. 0.010
250637.73-I.................................................. 0.030
254790.41-I*................................................. 0.050
258943.08-I**................................................0.100
263095.75-I*****............................................. 0.230
267248.44-I***********....................................... 0.370
271401.12-I******************................................0.530
275553.81-I**************************........................ 0.650
279706.50-I********************************.................. 0.770
283859.19-I**************************************............0.860
288011.88-I*******************************************.......0.940
292164.56-I***********************************************.... 0.990
296317.25-I*************************************************....1.000
300469.81-I**************************************************
       MAX-I----I----I----I----I----I----I----I----I----I----I----I
       TN-TYPE  = 26        MIN  =  248561.41      MODE VALUE=  273477.47
       NO.OF.OBS= 100       MAX  =  298393.47      MODE PROB =       0.160
                            MEAN =  275560.31      PEAR SKEW =     2082.84
                            S.D  =   10481.160     PEAR-COFF =       0.199
                            C.O.V=       0.038

              (f)-CDF OF COST OF IDLE TIME OF RESOURCES.
              ------------------------------------------
```

Figure (46)- (PDF) And (CDF) Of Total Idle Time Cost Of Resources (first run).

```
    0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
   MIN-I----I----I----I----I----I----I----I----I----I----I----I
2666264.00-I*............................................... 0.030
2672192.50-I*...............................................0.020
2678120.50-I*...............................................0.020
2684049.00-I*............................................... 0.030
2689977.00-I**********......................................0.200
2695905.50-I********........................................0.150
2701833.50-I******.......................................... 0.130
2707762.00-I******..........................................0.120
2713690.00-I********........................................ 0.170
2719618.50-I***.............................................0.070
2725546.50-I................................................0.000
2731475.00-I**.............................................. 0.050
2737402.50-I................................................0.010
   MAX-I----I----I----I----I----I----I----I----I----I----I----I
   TN-TYPE   = 26          MIN   = 2666264.00     MODE VALUE= 2689977.00
   NO.OF.OBS= 100          MAX   = 2737402.00     MODE PROB =      0.200
   COST-CONS= 2490000      MEAN  = 2701745.00     PEAR SKEW =   11762.00
   CII-INDEX=0.000         S.D   =   14679.317    PEAR-COFF =      0.802
                           C.O.V=       0.005

                  (g)-PDF OF TOTAL COST.
                  ----------------------
```

```
    0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
   MIN-I----I----I----I----I----I----I----I----I----I----I----I
                                                            0.000
2663300.00-I................................................ 0.030
2669228.20-I*............................................... 0.050
2675156.50-I**.............................................. 0.070
2681084.80-I***.............................................0.100
2687013.00-I*****...........................................0.300
2692941.20-I***************................................. 0.450
2698869.50-I**********************..........................0.580
2704797.80-I*****************************...................0.700
2710726.00-I**************************************.......... 0.870
2716654.20-I********************************************....0.940
2722582.50-I********************************************....0.940
2728510.80-I**********************************************.... 0.990
2734439.00-I***********************************************....1.000
2740366.00-I*************************************************----I
   MAX-I----I----I----I----I----I----I----I----I----I----I----I
   TN-TYPE   = 26          MIN   = 2666264.00     MODE VALUE= 2689977.00
   NO.OF.OBS= 100          MAX   = 2737402.00     MODE PROB =      0.200
   COST-CONS= 2490000      MEAN  = 2701745.00     PEAR SKEW =   11768.00
   CCVI-INDEX=0.000        S.D   =   14679.317    PEAR-COFF =      0.802
                           C.O.V=       0.005

                  (h)-CDF OF TOTAL COST.
                  ----------------------
```

Figure (47)- (PDF) And (CDF) Of Project Total Cost (first run).

A LIST OF ADNODES IN THE DESCENDING ORDER OF CI.
****

SEQ	NODE'S NUMBER	NODE'S TYPE	C-INDEX
1	2	28	1
2	10	10	1
3	330	12	1
4	35	10	1
5	340	11	1
6	575	11	1
7	2170	10	1
8	595	10	1
9	260	10	1
10	615	10	1
11	280	10	1
12	635	10	1
13	2235	12	1
14	165	10	1
15	180	10	1
16	190	10	1
17	200	10	1
18	210	10	1
19	220	18	1
20	464	10	1
21	240	10	1
22	470	11	1
23	325	10	1
24	735	10	1
25	335	10	1
26	745	11	1
27	290	11	1
28	2400	18	1
29	765	10	1
30	2410	26	1
31	545	10	1
32	460	10	1
33	565	10	1
34	350	10	1
35	2160	10	1
36	370	10	1
37	410	10	1
38	390	10	1
39	805	10	1
40	645	11	1
41	815	11	1
42	420	11	1
43	765	10	1
44	715	10	1
45	450	10	1
46	2155	12	1
47	2250	10	1
48	2405	10	1
49	980	10	.66
50	2050	10	.66
51	890	10	.66
52	880	10	.66
53	950	11	.66
54	920	10	66
55	895	11	.66
56	1020	18	.66
57	940	10	.66
58	2060	10	.66
59	905	10	.66
60	2130	12	.53
61	2146	10	.53
62	2138	10	.53
63	2075	10	.47
64	2095	10	.47
65	2085	10	.47
66	870	18	.34
67	1615	10	.34
68	855	10	.34
69	1695	12	.34
70	1650	10	.34
71	835	11	.34
72	521	12	0
73	235	10	0
74	115	10	0
75	680	10	0

Figure (48)-Project Activities In The Order Of Their Criticality Index (first run).

SEQ	NODE'S NUMBER	NODE'S TYPE	C-INDEX
76	80	10	0
77	710	10	0
78	150	18	0
79	610	10	0
80	490	11	0
81	505	10	0
82	700	18	0
83	285	11	0
84	640	11	0
85	630	10	0
86	90	10	0
87	15	10	0
88	560	10	0
89	40	10	0
90	570	11	0
91	60	12	0
92	590	10	0
93	85	10	0
94	365	10	0
95	110	10	0
96	405	10	0
97	120	10	0
98	415	11	0
99	305	10	0
100	315	10	0
101	665	11	0
102	935	10	0
103	685	10	0
104	463	10	0
105	955	11	0
106	465	11	0
107	975	10	0
108	485	11	0
109	1006	12	0
110	1010	10	0
111	510	10	0
112	1045	10	0
113	525	10	0
114	530	18	0
115	540	10	0
116	1090	10	0
117	1125	12	0
118	1150	10	0
119	1155	10	0
120	365	10	0
121	1180	10	0
122	1185	10	0
123	1190	10	0
124	1210	12	0
125	1240	10	0
126	1245	10	0
127	1250	10	0
128	660	11	0
129	1260	10	0
130	1290	12	0
131	1310	10	0
132	1315	10	0
133	1320	18	0
134	1330	10	0
135	1360	10	0
136	255	10	0
137	1370	10	0
138	275	10	0
139	1380	10	0
140	760	10	0
141	1435	10	0
142	1440	10	0
143	1445	10	0
144	1465	10	0
145	1470	10	0
146	1475	10	0
147	1495	12	0
148	1160	10	0
149	1530	10	0
150	850	10	0
151	1540	10	0
152	1545	10	0

Figure (48)- Continued.

SEQ	NODE'S NUMBER	NODE'S TYPE	C-INDEX
153	1575	12	0
154	1595	10	0
155	1600	10	0
156	1255	10	0
157	435	10	0
158	1645	10	0
159	445	10	0
160	1655	10	0
161	1660	10	0
162	1665	10	0
163	960	10	0
164	1720	10	0
165	1725	10	0
166	1730	10	0
167	1750	10	0
168	1755	10	0
169	1760	10	0
170	1780	12	0
171	1810	10	0
172	1815	10	0
173	1820	10	0
174	1825	10	0
175	1830	10	0
176	1860	12	0
177	1880	10	0
178	1885	10	0
179	1890	18	0
180	1900	10	0
181	1920	10	0
182	1925	10	0
183	1930	10	0
184	1950	12	0
185	1960	10	0
186	1970	10	0
187	1995	10	0
188	2000	10	0
189	2005	10	0
190	2010	10	0
191	2030	12	0
192	2040	10	0
193	1365	10	0
194	730	10	0
195	1375	10	0
196	740	11	0
197	1410	12	0
198	2115	10	0
199	2120	10	0
200	780	10	0
201	2136	10	0
202	800	10	0
203	2144	10	0
204	810	11	0
205	1525	10	0
206	830	11	0
207	1535	10	0
208	2185	18	0
209	2195	10	0
210	2205	10	0
211	2215	10	0
212	2225	10	0
213	1805	18	0
214	915	10	0
215	2255	10	0
216	2270	10	0
217	2275	10	0
218	2280	10	0
219	2295	10	0
220	2310	10	0
221	2315	10	0
222	2340	10	0
223	2345	10	0
224	2350	10	0
225	2355	10	0
226	2380	10	0
227	2385	10	0
228	1075	10	0
229	1080	10	0
230	1085	[illegible]	[illegible]
231	1090		

Figure (48)- Continued.

COPY OF SUMMARY REPORT ON LABOUR RESOURCE.

THE NUMBER OF LABOUR RESOURCE CATEGORIES= 21

CATEGORY NO	NO.OF QNODES
1	3
2	2
3	2
4	6
5	4
6	5
7	13
8	5
9	4
10	[illegible]
11	[illegible]
12	[illegible]
13	8
14	[illegible]
15	[illegible]
16	[illegible]
17	24
18	15
19	5
20	[illegible]
21	9

SEQ	CATEGORY NUMBER	NO.OF NODES	UNIT RATE /TIME UNIT	IDLE TIME MEAN	IDLE TIME S.D	MEAN VALUE I.T.(COST)
1	18	15	150	421.97	16.946	63295.480
2	20	7	150	205.53	15.242	30830.008
3	12	7	200	116.05	4.777	23210.176
4	11	9	300	70.71	2.783	21213.359
5	13	8	200	101.45	5.872	20289.879
6	16	7	400	45.34	2.534	18134.525
7	17	24	150	115.86	8.640	17379.402
8	15	11	150	107.27	6.253	16089.961
9	14	9	150	67.14	9.846	10071.181
10	10	8	600	5.02	1.010	3010.582
11	8	5	300	0.00	0.000	0.000
12	7	13	1200	0.00	0.000	0.000
13	6	5	1000	0.00	0.000	0.000
14	4	6	150	0.00	0.000	0.000
15	21	9	50	0.00	0.000	0.000
16	19	5	300	0.00	0.000	0.000
17	[illegible]	[illegible]	[illegible]	0.00	0.000	0.000
18	[illegible]	[illegible]	[illegible]	0.00	0.000	0.000
19	9	4	300	0.00	0.000	0.000
20	5	4	550	0.00	0.000	0.000
21	1	3	250	0.00	0.000	0.000

Figure (49)- Summary Report On Labour Resources (first run).

COPY OF SUMMARY REPORT ON MACHINARY RESOURCE.
****

THE NUMBER OF MACHINARY RESOURCE CATEGORIES= 7

CATEGORY NO	NO.OF.QNODES
1	4
2	5
3	4
4	2
5	2
6	15
7	18

SEQ	CATEGORY NUMBER	NO.OF NODES	UNIT RATE /TIME UNIT	IDLE TIME MEAN	IDLE TIME S.D	MEAN VALUE I.T.(COST)
1	1	4	2600	0.00	0.000	0.000
2	2	5	1200	0.00	0.000	0.000
3	3	4	1600	0.00	0.000	0.000
4	4	2	1900	0.00	0.000	0.000
5	5	2	2000	0.00	0.000	0.000
6	6	18	1200	0.00	0.000	0.000
7	7	15	2100	0.00	0.000	0.000

Figure (50)- Summary Report On Machinery Resources (first run).

COPY OF DETAILED REPORT ON LABOUR RESOURCE CATEGORY: 18
****

CATEGORY DESCRIPTION:TILING-C
THE NUMBER OF LQNODES= 15
UNIT RATE/TIME UNIT= 150

	MIN	MAX	MEAN	S.D
IDLE TIME :	377.78	460.87	421.97	16.946
IDLE TIME COST:	56667.16	69130.95	63295.48	2541.853

COPY OF DETAILED REPORT ON THE QNODES OF LABOUR RESOURCE CATEGORY: 18
****

1 NODE'S NUMBER: 2
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1150
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1160
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

2 NODE'S NUMBER: 4
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1155
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1185
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

3 NODE'S NUMBER: 6
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1160
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1190
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

4 NODE'S NUMBER: 8
NODE'S TYPE IS Q-SINGLE
PRE-NODE'S NUMBER: 1180
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1465
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	3.11	12.55	6.76	2.116

Figure (51)- Detailed Report On Tiling Crew (I-18) (first run).

5 NODE'S NUMBER: 10
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1185
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1755
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	104.69	135.98	121.25	6.228

6 NODE'S NUMBER: 12
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1190
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1470
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	35.50	58.88	45.13	5.064

7 NODE'S NUMBER: 14
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1465
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1750
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	20.29	37.41	29.43	3.159

8 NODE'S NUMBER: 16
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1755
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1760
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	31.10	49.89	39.65	4.425

9 NODE'S NUMBER: 18
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1470
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1475
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	[illegible]	45.35	35.52	3.751

10 NODE'S NUMBER: 20
NODE'S TYPE IS:SINK
PRE-NODE'S NUMBER: 1750
PRE-NODE'S TYPE : 10
THE NUMBER OF UNITS= 2

	MIN	MAX	MEAN	S.D
RELEASING TIME:	183.[illegible]	195.56	189.[illegible]	2.021

Figure (51)- Continued.

```
11 NODE'S NUMBER: 22
   NODE'S TYPE IS:Q-SINGLE
   PRE-NODE'S NUMBER: 1760
   PRE-NODE'S TYPE   : 10
   SUCC-NODE'S NUMBER: 1970
   SUCC-NODE'S TYPE  : 10
```

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

```
12 NODE'S NUMBER: 24
   NODE'S TYPE IS:Q-SINGLE
   PRE-NODE'S NUMBER: 1475
   PRE-NODE'S TYPE   : 10
   SUCC-NODE'S NUMBER: 2085
   SUCC-NODE'S TYPE  : 10
```

	MIN	MAX	MEAN	S.D
IDLE TIME :	40.12	81.46	60.68	8.479

```
13 NODE'S NUMBER: 26
   NODE'S TYPE IS:SINK
   PRE-NODE'S NUMBER: 1970
   PRE-NODE'S TYPE   : 10
   THE NUMBER OF UNITS= 3
```

	MIN	MAX	MEAN	S.D
RELEASING TIME:	221.23	235.26	228.42	2.789

```
14 NODE'S NUMBER: 28
   NODE'S TYPE IS:Q-SINGLE
   PRE-NODE'S NUMBER: 2085
   PRE-NODE'S TYPE   : 10
   SUCC-NODE'S NUMBER: 2250
   SUCC-NODE'S TYPE  : 10
```

	MIN	MAX	MEAN	S.D
IDLE TIME :	77.49	91.89	83.55	3.080

```
15 NODE'S NUMBER: 30
   NODE'S TYPE IS:SINK
   PRE-NODE'S NUMBER: 2250
   PRE-NODE'S TYPE   : 10
   THE NUMBER OF UNITS= 3
```

	MIN	MAX	MEAN	S.D
RELEASING TIME:	253.76	268.97	261.33	3.058

Figure (51)- Continued.

COPY OF SCHEDULE OF LABOUR RESOURCE CATEGORY: 18
****

SEQ	NODE NO	NODE TYPE	NO. OF UNITS	PARA TITLE	PARA TYPE	MIN	MAX	M-L MEAN	S.D	C-I
1	1180	ACT	2	STR-T E-DUR	BETA	138.57 7.00	148.57 9.50	144.19 8.00	1.931	0.00
2	1185	ACT	3	STR-T E-DUR	BETA	141.46 6.50	151.92 8.00	147.19 7.00	2.059	0.00
3	1190	ACT	3	STR-T E-DUR	UNIF	148.25 6.00	159.92 7.00	154.50	2.010	0.00
4	1465	ACT	2	STR-T E-DUR	BETA	150.17 7.00	160.35 9.50	165.66 8.00	1.849	0.00
5	1755	ACT	3	STR-T E-DUR	UNIF	188.71 6.00	199.64 7.00	194.70	2.202	0.00
6	1470	ACT	3	STR-T E-DUR	UNIF	170.16 7.00	181.73 8.50	176.01	2.417	0.00
7	1750	ACT	2	STR-T E-DUR	BETA	173.15 10.00	183.66 13.00	175.46 11.00	1.879	0.00
8	1760	ACT	3	STR-T E-DUR	UNIF	206.72 5.00	221.42 6.00	214.44	2.804	0.00
9	1475	ACT	3	STR-T E-DUR	UNIF	188.54 5.00	203.28 6.00	195.53	2.591	0.00
10	20	SINK	2	REL-T		183.70	195.56	189.68	2.021	
11	1970	ACT	3	STR-T E-DUR	UNIF	212.40 8.00	226.81 9.00	219.93	2.822	0.00
12	2085	ACT	3	STR-T E-DUR	UNIF	214.44 2.50	227.94 3.00	221.26	2.771	0.47
13	26	SINK	3	REL-T		221.23	235.26	228.42	2.789	
14	2250	ACT	3	STR-T E-DUR	UNIF	244.60 9.00	259.13 10.00	251.85	3.018	1.00
15	30	SINK	3	REL-T		253.76	268.97	261.33	3.058	

Figure (52)- Schedule Of Tiling Crew (first run).

COPY OF DETAILED REPORT ON LABOUR RESOURCE CATEGORY: 20
****

CATEGORY DESCRIPTION:PAINTING-C
THE NUMBER OF LQNODES= 7
UNIT RATE/TIME UNIT= 150

	MIN	MAX	MEAN	S.D
IDLE TIME :	176.79	242.06	205.53	15.242
IDLE TIME COST:	26518.40	36309.61	30830.01	2286.289

COPY OF DETAILED REPORT ON THE QNODES OF LABOUR RESOURCE CATEGORY: 20
****

1 NODE'S NUMBER: 2
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1290
PRE-NODE'S TYPE : 12
SUCC-NODE'S NUMBER: 1310
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

2 NODE'S NUMBER: 4
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1310
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1595
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	115.80	179.09	153.11	13.248

3 NODE'S NUMBER: 6
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1595
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1880
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	8.83	101.81	52.43	19.932

4 NODE'S NUMBER: 8
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1880
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 2040
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

Figure (53)- Detailed Report On Painting Crew (L-20) (first run).

```
5  NODE'S NUMBER: 10
   NODE'S TYPE IS:SINK
   PRE-NODE'S NUMBER: 1880
   PRE-NODE'S TYPE   : 10
   THE NUMBER OF UNITS= 4
------------------------------------------
                        MIN        MAX        MEAN        S.D
                     ---------  ---------  ----------  -------
RELEASING TIME:        232.47     247.18     238.86      3.038
---------------------------------------------------------------------

6  NODE'S NUMBER: 12
   NODE'S TYPE IS:Q-SINGLE
   PRE-NODE'S NUMBER: 2040
   PRE-NODE'S TYPE   : 10
   SUCC-NODE'S NUMBER: 2115
   SUCC-NODE'S TYPE  : 10
------------------------------------------
                        MIN        MAX        MEAN        S.D
                     ---------  ---------  ----------  -------
IDLE TIME      :         0.00       0.00       0.00      0.000
---------------------------------------------------------------------

7  NODE'S NUMBER: 14
   NODE'S TYPE IS:SINK
   PRE-NODE'S NUMBER: 2115
   PRE-NODE'S TYPE   : 10
   THE NUMBER OF UNITS= 2
------------------------------------------
                        MIN        MAX        MEAN        S.D
                     ---------  ---------  ----------  -------
RELEASING TIME:        240.06     254.27     246.35      3.035
---------------------------------------------------------------------
```

COPY OF SCHEDULE OF LABOUR RESOURCE CATEGORY: 20
****

SEQ	NODE NO	NODE TYPE	NO.OF UNITS	PARA TITLE	PARA TYPE	MIN	MAX	M-L MEAN	S.D	C-I
1	1310	ACT	6	STR-T E-DUR	TRIA	171.53 6.00	182.31 7.00	177.68 6.50	1.984	0.00
2	1595	ACT	6	STR-T E-DUR	TRIA	201.68 9.00	216.31 12.00	209.69 10.00	2.554	0.00
3	1880	ACT	6	STR-T E-DUR	TRIA	221.64 8.50	236.37 12.00	228.62 10.00	3.030	0.00
4	2040	ACT	2	STR-T E-DUR	UNIF	232.47 4.50	247.18 5.00	238.86	3.038	0.00
5	10	SINK	4	REL-T		232.47	247.18	238.86	3.038	
6	2115	ACT	2	STR-T E-DUR	UNIF	237.26 2.50	251.77 3.00	243.61	3.045	0.00
7	14	SINK	2	REL-T		240.06	254.27	246.35	3.035	

Figure (54)- Schedule For The Painting Crew (L-20) (first run).

COPY OF DETAILED REPORT ON LABOUR RESOURCE CATEGORY: 12
****

CATEGORY DESCRIPTION:METAL-D+W(CREW)
THE NUMBER OF LQNODES= 7
UNIT RATE/TIME UNIT= 200

	MIN	MAX	MEAN	S.D
IDLE TIME :	104.13	127.67	116.05	4.777
IDLE TIME COST:	20825.54	25534.64	23210.18	955.371

COPY OF DETAILED REPORT ON THE QNODES OF LABOUR RESOURCE CATEGORY: 12
****

1 NODE'S NUMBER: 2
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1045
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1090
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

2 NODE'S NUMBER: 4
NODE'S TYPE IS:SINK
PRE-NODE'S NUMBER: 1090
PRE-NODE'S TYPE : 10
THE NUMBER OF UNITS= 2

	MIN	MAX	MEAN	S.D
RELEASING TIME:	126.41	135.29	131.22	1.824

3 NODE'S NUMBER: 6
NODE'S TYPE IS:Q-MULTIPLE
PRE-NODE'S NUMBER: 1900
PRE-NODE'S TYPE : 10

THE NUMBER OF SUCC-QNODES= 4

SEQ	SUCC-NODE'S NO	SUCC-NODE'S TYPE
1	1920.	10.
2	1255.	10.
3	1995.	10.
4	8.	9.

	MIN	MAX	MEAN	S.D
IDLE TIME :	104.13	127.67	116.05	4.777

Figure (55)- Detailed Report On Metal D+W Crew (L-12)(first run).

4 NODE'S NUMBER: 8
NODE'S TYPE IS:SINK
PRE-NODE'S NUMBER: 6
PRE-NODE'S TYPE : 8
THE NUMBER OF UNITS= 1

	MIN	MAX	MEAN	S.D
RELEASING TIME:	221.23	235.26	228.46	2.810

5 NODE'S NUMBER: 10
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1995
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 2345
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

6 NODE'S NUMBER: 12
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 2345
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 2355
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

7 NODE'S NUMBER: 14
NODE'S TYPE IS:SINK
PRE-NODE'S NUMBER: 2355
PRE-NODE'S TYPE : 10
THE NUMBER OF UNITS= 1

	MIN	MAX	MEAN	S.D
RELEASING TIME:	227.23	241.26	234.42	2.787

COPY OF SCHEDULE OF LABOUR RESOURCE CATEGORY: 12
****

SEQ	NODE NO	NODE TYPE	NO.OF UNITS	PARA TITLE	PARA TYPE	MIN	MAX	M-L MEAN	S.D	C-I
1	1090	ACT	2	STR-T E-DUR	 UNIF	122.28 4.00	130.02 6.00	126.30	1.676	0.00
2	4	SINK	2	REL-T		126.41	135.29	131.22	1.824	
3	1920	ACT	2	STR-T E-DUR	 CONS	156.86 1.00	173.43	165.94	4.066	0.00
4	1255	ACT	2	STR-T E-DUR	 UNIF	157.74 6.00	167.17 8.50	162.73	1.831	0.00
5	1995	ACT	1	STR-T E-DUR	 CONS	221.23 2.00	235.26	228.42	2.789	0.00
6	8	SINK	1	REL-T		221.23	235.26	228.46	2.810	
7	2345	ACT	1	STR-T E-DUR	 CONS	223.23 2.00	237.26	230.42	2.780	0.00
8	2355	ACT	1	STR-T E-DUR	 CONS	225.23 2.00	239.26	232.42	2.787	0.00
9	14	SINK	1	REL-T		227.23	241.26	234.42	2.787	

Figure (56)- Schedule For Metal D+W Crew (L-12) (first run).

COPY OF DETAILED REPORT ON LABOUR RESOURCE CATEGORY: 11
****

CATEGORY DESCRIPTION:E.W-CREW
THE NUMBER OF LQNODES= 9
UNIT RATE/TIME UNIT= 300

	MIN	MAX	MEAN	S.D
IDLE TIME :	64.78	78.24	70.71	2.783
IDLE TIME COST:	19432.54	23471.22	21213.36	834.954

COPY OF DETAILED REPORT ON THE QNODES OF LABOUR RESOURCE CATEGORY: 11
****

1 NODE'S NUMBER: 2
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1045
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1075
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

2 NODE'S NUMBER: 4
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1075
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1360
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	4.08	8.37	6.39	0.793

3 NODE'S NUMBER: 6
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1360
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1645
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	9.16	16.09	13.14	1.407

Figure (57)- Detailed Report On The Electrical Works Crew (L-11)(first run).

```
 4  NODE'S NUMBER: 8
    NODE'S TYPE IS:Q-SINGLE
    PRE-NODE'S NUMBER: 1645
    PRE-NODE'S TYPE   : 10
    SUCC-NODE'S NUMBER: 1930
    SUCC-NODE'S TYPE  : 10
---------------------------------------------
                          MIN         MAX         MEAN        S.D
                       ---------   ---------   ----------   -------
IDLE TIME     :          0.00        0.00        0.00        0.000
--------------------------------------------------------------------------

 5  NODE'S NUMBER: 10
    NODE'S TYPE IS:Q-SINGLE
    PRE-NODE'S NUMBER: 1930
    PRE-NODE'S TYPE   : 10
    SUCC-NODE'S NUMBER: 1240
    SUCC-NODE'S TYPE  : 10
---------------------------------------------
                          MIN         MAX         MEAN        S.D
                       ---------   ---------   ----------   -------
IDLE TIME     :          0.00        0.00        0.00        0.000
--------------------------------------------------------------------------

 6  NODE'S NUMBER: 12
    NODE'S TYPE IS:Q-SINGLE
    PRE-NODE'S NUMBER: 1240
    PRE-NODE'S TYPE   : 10
    SUCC-NODE'S NUMBER: 1525
    SUCC-NODE'S TYPE  : 10
---------------------------------------------
                          MIN         MAX         MEAN        S.D
                       ---------   ---------   ----------   -------
IDLE TIME     :         24.46       34.25       30.02        2.098
--------------------------------------------------------------------------

 7  NODE'S NUMBER: 14
    NODE'S TYPE IS:Q-SINGLE
    PRE-NODE'S NUMBER: 1525
    PRE-NODE'S TYPE   : 10
    SUCC-NODE'S NUMBER: 1810
    SUCC-NODE'S TYPE  : 10
---------------------------------------------
                          MIN         MAX         MEAN        S.D
                       ---------   ---------   ----------   -------
IDLE TIME     :          8.60       21.57       15.42        2.865
--------------------------------------------------------------------------

 8  NODE'S NUMBER: 16
    NODE'S TYPE IS:Q-SINGLE
    PRE-NODE'S NUMBER: 1810
    PRE-NODE'S TYPE   : 10
    SUCC-NODE'S NUMBER: 2005
    SUCC-NODE'S TYPE    10
---------------------------------------------
                          MIN         MAX         MEAN        S.D
                       ---------   ---------   ----------   -------
IDLE TIME     :          5.04        6.45        5.74        0.310
--------------------------------------------------------------------------
```

Figure (57)- Continued.

```
9   NODE'S NUMBER: 18
    NODE'S TYPE IS:SINK
    PRE-NODE'S NUMBER: 2005
    PRE-NODE'S TYPE  : 10
    THE NUMBER OF UNITS= 1
```

	MIN	MAX	MEAN	S.D
RELEASING TIME:	222.23	236.26	229.42	2.788

COPY OF SCHEDULE OF LABOUR RESOURCE CATEGORY: 11
****

SEQ	NODE NO	NODE TYPE	NO.OF UNITS	PARA TITLE	PARA TYPE	MIN	MAX	M-L MEAN	S.D	C-[
1	1075	ACT	1	STR-T E-DUR	UNIF	122.28 6.00	130.02 8.00	126.30	1.676	0.00
2	1360	ACT	1	STR-T E-DUR	UNIF	134.79 6.00	143.34 8.00	139.70	1.749	0.00
3	1645	ACT	1	STR-T E-DUR	UNIF	154.21 5.00	164.64 6.50	159.69	1.805	0.00
4	1930	ACT	1	STR-T E-DUR	CONS	160.33 2.00	170.22	165.50	1.838	0.00
5	1240	ACT	1	STR-T E-DUR	UNIF	162.33 3.00	172.22 4.00	167.50	1.842	0.00
6	1525	ACT	1	STR-T E-DUR	UNIF	193.77 3.00	208.58 4.00	201.03	2.568	0.00
7	1810	ACT	1	STR-T E-DUR	UNIF	212.40 2.50	226.81 3.00	219.93	2.822	0.00
8	2005	ACT	1	STR-T E-DUR	CONS	221.23 1.00	235.26	228.42	2.789	0.00
9	18	SINK	1	REL-T		222.23	236.26	229.42	2.788	

Figure (58) Schedule Of Electrical Works Crew (L-11)(first run).

COPY OF DETAILED REPORT ON LABOUR RESOURCE CATEGORY: 13
****

CATEGORY DESCRIPTION:WOODEN-D
THE NUMBER OF LQNODES= 7
UNIT RATE/TIME UNIT= 200

	MIN	MAX	MEAN	S.D
IDLE TIME :	86.62	114.91	101.45	5.872
IDLE TIME COST:	17323.92	22982.37	20289.88	1174.385

COPY OF DETAILED REPORT ON THE QNODES OF LABOUR RESOURCE CATEGORY: 13
****

1 NODE'S NUMBER: 2
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1330
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1095
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

2 NODE'S NUMBER: 4
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1095
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1380
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

3 NODE'S NUMBER: 6
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1380
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1665
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	7.81	15.64	11.31	1.392

4 NODE'S NUMBER: 8
NODE'S TYPE IS:SINK
PRE-NODE'S NUMBER: 1665
PRE-NODE'S TYPE : 10
THE NUMBER OF UNITS= 1

	MIN	MAX	MEAN	S.D
RELEASING TIME:	159.94	171.10	165.50	1.779

Figure (59)- Detailed Report On Wooden Doors Crew (L-13)(first run).

5 NODE'S NUMBER: 10
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1210
PRE-NODE'S TYPE : 12
SUCC-NODE'S NUMBER: 1260
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

6 NODE'S NUMBER: 12
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1260
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1545
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	60.58	78.80	69.66	4.201

7 NODE'S NUMBER: 14
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1545
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1830
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	7.15	34.75	20.48	5.762

8 NODE'S NUMBER: 16
NODE'S TYPE IS:SINK
PRE-NODE'S NUMBER: 1830
PRE-NODE'S TYPE : 10
THE NUMBER OF UNITS= 2

	MIN	MAX	MEAN	S.D
RELEASING TIME:	218.35	231.86	225.64	2.872

COPY OF SCHEDULE OF LABOUR RESOURCE CATEGORY: 13
****

SEQ	NODE NO	NODE TYPE	NO.OF UNITS	PARA TITLE	PARA TYPE	MIN	MAX	M-L MEAN	S.D	C-I
1	1095	ACT	1	STR-T E-DUR	UNIF	130.16 3	140.24 4	135.61	1.688	0.00
2	1380	ACT	1	STR-T E-DUR	UNIF	134.79 7.50	143.34 10.00	139.70	1.749	0.00
3	1665	ACT	1	STR-T E-DUR	UNIF	154.21 5.00	164.64 6.50	159.69	1.805	0.00
4	8	SINK	1	REL T		159.94	171.10	165.50	1.779	
5	1260	ACT	2	STR-T E-DUR	UNIF	154.83 4.50	166.42 6.00	160.97	2.022	0.00
6	1545	ACT	2	STR-T E-DUR	UNIF	193.77 7.50	208.58 10.00	201.03	2.568	0.00
7	1830	ACT	2	STR-T E-DUR	UNIF	212.40 5.00	226.81 6.50	219.93	2.822	0.00
8	16	SINK	2	REL T		218.35	231.86	225.64	2.872	

Figure (60)- Schedule For Wooden Doors Crew (L-13)(first run).

COPY OF DETAILED REPORT ON LABOUR RESOURCE CATEGORY: 16
****

CATEGORY DESCRIPTION:C-HEATING(CREW)
THE NUMBER OF LQNODES= 7
UNIT RATE/TIME UNIT= 400

	MIN	MAX	MEAN	S.D
IDLE TIME :	38.41	50.58	45.34	2.534
IDLE TIME COST:	15362.89	20233.93	18134.53	1013.734

COPY OF DETAILED REPORT ON THE QNODES OF LABOUR RESOURCE CATEGORY: 16
****

1 NODE'S NUMBER: 2
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1045
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1080
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

2 NODE'S NUMBER: 4
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1080
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1365
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	1.96	0.36	0.556

3 NODE'S NUMBER: 6
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1365
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1650
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	3.69	10.89	7.56	1.373

4 NODE'S NUMBER: 8
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1650
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1245
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

Figure (61)- Detailed Report On Central Heating Crew (L-16)(first run).

```
5  NODE'S NUMBER: 10
   NODE'S TYPE IS:Q-SINGLE
   PRE-NODE'S NUMBER: 1245
   PRE-NODE'S TYPE  : 10
   SUCC-NODE'S NUMBER: 1530
   SUCC-NODE'S TYPE  : 10
```

	MIN	MAX	MEAN	S.D
IDLE TIME :	17.05	27.70	23.35	2.171

```
6  NODE'S NUMBER: 12
   NODE'S TYPE IS:Q-SINGLE
   PRE-NODE'S NUMBER: 1530
   PRE-NODE'S TYPE  : 10
   SUCC-NODE'S NUMBER: 1815
   SUCC-NODE'S TYPE  : 10
```

	MIN	MAX	MEAN	S.D
IDLE TIME :	7.32	19.90	14.06	2.811

```
7  NODE'S NUMBER: 14
   NODE'S TYPE IS:SINK
   PRE-NODE'S NUMBER: 1815
   PRE-NODE'S TYPE  : 10
   THE NUMBER OF UNITS= 1
```

	MIN	MAX	MEAN	S.D
RELEASING TIME:	216.93	232.34	224.86	2.819

COPY OF SCHEDULE OF LABOUR RESOURCE CATEGORY: 16

SEQ	NODE NO	NODE TYPE	NO.OF UNITS	PARA TITLE	PARA TYPE	MIN	MAX	M-L MEAN	S.D	C-I
1	1080	ACT	1	STR-T E-DUR	UNIF	122.28 12.00	130.02 15.00	126.30	1.676	0.00
2	1365	ACT	1	STR-T E-DUR	UNIF	135.21 11.00	144.19 13.00	140.22	1.794	0.00
3	1650	ACT	1	STR-T E-DUR	UNIF	154.21 11.00	164.64 13.00	159.69	1.805	0.34
4	1245	ACT	1	STR-T E-DUR	UNIF	165.82 5.00	176.33 7.00	171.71	1.968	0.00
5	1530	ACT	1	STR-T E-DUR	UNIF	193.77 4.00	208.58 5.50	201.03	2.568	0.00
6	1815	ACT	1	STR-T E-DUR	UNIF	212.40 4.00	226.81 6.00	219.93	2.822	0.00
7	14	SINK	1	REL-T		216.93	232.34	224.86	2.819	

Figure (62)- Schedule For The Central Heating Crew (L-16)(first run).

COPY OF DETAILED REPORT ON LABOUR RESOURCE CATEGORY: 17
****

CATEGORY DESCRIPTION:PLASTERING-C
THE NUMBER OF LQNODES= 24
UNIT RATE/TIME UNIT= 150

	MIN	MAX	MEAN	S.D
IDLE TIME :	93.07	137.02	115.86	8.640
IDLE TIME COST:	13959.88	20553.05	17379.40	1295.931

COPY OF DETAILED REPORT ON THE QNODES OF LABOUR RESOURCE CATEGORY: 17
****

1 NODE'S NUMBER: 2
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1125
PRE-NODE'S TYPE : 12
SUCC-NODE'S NUMBER: 1150
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

2 NODE'S NUMBER: 4
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1125
PRE-NODE'S TYPE : 12
SUCC-NODE'S NUMBER: 1160
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

3 NODE'S NUMBER: 6
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1125
PRE-NODE'S TYPE : 12
SUCC-NODE'S NUMBER: 1155
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

4 NODE'S NUMBER: 8
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1150
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1435
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME	12.34	20.37	15.99	1.898

Figure (63)- Detailed Report On Plastering Crew (L-17)(first run).

5 NODE'S NUMBER: 10
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1160
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1725
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	39.43	63.16	51.65	4.946

6 NODE'S NUMBER: 12
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1155
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1440
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	7.85	23.03	14.83	2.988

7 NODE'S NUMBER: 14
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1435
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1720
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	24.29	38.96	32.11	2.912

8 NODE'S NUMBER: 16
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1725
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1730
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

9 NODE'S NUMBER: 18
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1440
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1445
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

Figure (63)- Continued.

15 NODE'S NUMBER: 30
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1960
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 2144
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

16 NODE'S NUMBER: 32
NODE'S TYPE IS:SINK
PRE-NODE'S NUMBER: 2144
PRE-NODE'S TYPE : 10
THE NUMBER OF UNITS= 3

	MIN	MAX	MEAN	S.D
RELEASING TIME:	206.38	219.92	212.71	2.643

17 NODE'S NUMBER: 34
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 2138
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 2340
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

18 NODE'S NUMBER: 36
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 2146
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 2160
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	8.21	1.39	2.015

19 NODE'S NUMBER: 38
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 2340
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 2350
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

Figure (63)- Continued.

20 NODE'S NUMBER: 40
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 2160
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 2170
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

21 NODE'S NUMBER: 42
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 2350
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 2380
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

22 NODE'S NUMBER: 44
NODE'S TYPE IS:SINK
PRE-NODE'S NUMBER: 2170
PRE-NODE'S TYPE : 10
THE NUMBER OF UNITS= 3

	MIN	MAX	MEAN	S.D
RELEASING TIME:	244.60	259.13	251.85	3.018

23 NODE'S NUMBER: 46
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 2380
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 2385
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME	0.00	0.00	0.00	0.000

24 NODE'S NUMBER: 48
NODE'S TYPE IS:SINK
PRE-NODE'S NUMBER: 2385
PRE-NODE'S TYPE : 10
THE NUMBER OF UNITS= 2

	MIN	MAX	MEAN	S.D
RELEASING TIME:	201.37	212.77	207.64	1.993

Figure (63)- Continued.

COPY OF SCHEDULE OF LABOUR RESOURCE CATEGORY: 17
****

SEQ	NODE NO	NODE TYPE	NO.OF UNITS	PARA TITLE	PARA TYPE	MIN	MAX	M-L MEAN	S.D	C-I
1	1150	ACT	2	STR-T E-DUR	 UNIF	134.43 3.50	144.19 5.00	139.86	1.935	0.00
2	1160	ACT	3	STR-T E-DUR	 TRIA	134.43 13.00	144.19 17.00	139.86 14.00	1.935	0.00
3	1155	ACT	3	STR-T E-DUR	 TRIA	134.43 6.00	144.19 9.00	139.86 7.00	1.935	0.00
4	1435	ACT	2	STR-T E-DUR	 UNIF	146.74 3.00	156.99 4.00	152.13	1.840	0.00
5	1725	ACT	3	STR-T E-DUR	 TRIA	165.82 20.00	176.33 27.00	171.71 22.00	1.868	0.00
6	1440	ACT	3	STR-T E-DUR	 TRIA	146.74 21.00	156.99 28.00	152.13 23.00	1.840	0.00
7	1720	ACT	2	STR-T E-DUR	 UNIF	165.82 5.50	176.33 8.00	171.71	1.868	0.00
8	1730	ACT	3	STR-T E-DUR	 TRIA	188.71 17.00	199.64 23.00	194.70 19.00	2.202	0.00
9	1445	ACT	3	STR-T E-DUR	 TRIA	170.16 17.00	181.73 23.00	176.01 19.00	2.417	0.00
10	2136	ACT	2	STR-T E-DUR	 UNIF	173.15 4.00	183.66 5.00	178.46	1.879	0.00
11	2075	ACT	3	STR-T E-DUR	 TRIA	206.72 5.50	221.46 8.00	214.44 7.00	2.804	0.47
12	1960	ACT	3	STR-T E-DUR	 TRIA	188.54 5.50	203.28 9.00	195.53 7.00	2.591	0.00
13	2138	ACT	2	STR-T E-DUR	 UNIF	178.03 4.00	188.48 5.00	182.97	1.854	0.53
14	2146	ACT	3	STR-T E-DUR	 TRIA	214.44 12.00	227.94 15.00	221.26 13.00	2.771	0.53
15	2144	ACT	3	STR-T E-DUR	 TRIA	195.10 9.00	209.79 12.00	202.39 10.00	2.584	0.00
16	32	SINK	3	REL-T		206.38	219.92	212.71	2.643	
17	2340	ACT	2	STR-T E-DUR	 TRIA	182.08 6.50	192.57 8.50	187.45 7.00	1.877	0.00
18	2160	ACT	3	STR-T E-DUR	 TRIA	229.03 10.00	241.43 13.00	235.08 11.00	2.961	1.00
19	2350	ACT	2	STR-T E-DUR	 TRIA	189.21 6.50	199.59 8.50	194.79 7.00	1.927	0.00
20	2170	ACT	3	STR-T E-DUR	 UNIF	239.45 5.00	253.92 6.00	246.39	3.032	1.00
21	2380	ACT	2	STR-T E-DUR	 UNIF	196.20 2.50	207.37 3.00	202.13	1.957	0.00
22	44	SINK	3	REL-T		244.60	259.13	251.85	3.018	
23	2385	ACT	2	STR-T E-DUR	 UNIF	198.78 2.50	210.00 3.00	204.88	1.979	0.00
24	48	SINK	2	REL-T		[illegible]	[illegible]	[illegible]	1.993	

Figure (64)- Schedule For The Plastering Crew (L-17) (first run).

COPY OF DETAILED REPORT ON LABOUR RESOURCE CATEGORY: 15
****

CATEGORY DESCRIPTION:PLUMBING-C
THE NUMBER OF LQNODES= 11
UNIT RATE/TIME UNIT= 150

	MIN	MAX	MEAN	S.D
IDLE TIME :	93.23	120.81	107.27	6.253
IDLE TIME COST:	13964.21	18121.27	16089.96	937.957

COPY OF DETAILED REPORT ON THE QNODES OF LABOUR RESOURCE CATEGORY: 15
****

1 NODE'S NUMBER: 2
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1045
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1085
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

2 NODE'S NUMBER: 4
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1085
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1370
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	2.66	6.06	4.40	0.755

3 NODE'S NUMBER: 6
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1370
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1655
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	10.25	17.22	14.36	1.374

Figure (65)- Detailed Report On The Plumbing Crew (L-15) (first run).

```
4  NODE'S NUMBER: 8
   NODE'S TYPE IS:Q-SINGLE
   PRE-NODE'S NUMBER: 1655
   PRE-NODE'S TYPE  : 10
   SUCC-NODE'S NUMBER: 1925
   SUCC-NODE'S TYPE  : 10
--------------------------------------------------
                     MIN        MAX        MEAN        S.D
                  ---------  ---------  ----------  -------
IDLE TIME    :       0.00       0.00       0.00       0.000
--------------------------------------------------------------------

5  NODE'S NUMBER: 10
   NODE'S TYPE IS:SINK
   PRE-NODE'S NUMBER: 1925
   PRE-NODE'S TYPE  : 10
   THE NUMBER OF UNITS= 1
--------------------------------------------------
                     MIN        MAX        MEAN        S.D
                  ---------  ---------  ----------  -------
RELEASING TIME:    163.67     173.98     168.63       2.023
--------------------------------------------------------------------

6  NODE'S NUMBER: 12
   NODE'S TYPE IS:Q-SINGLE
   PRE-NODE'S NUMBER: 1210
   PRE-NODE'S TYPE  : 12
   SUCC-NODE'S NUMBER: 1250
   SUCC-NODE'S TYPE  : 10
--------------------------------------------------
                     MIN        MAX        MEAN        S.D
                  ---------  ---------  ----------  -------
IDLE TIME    :       0.00       0.00       0.00       0.000
--------------------------------------------------------------------

7  NODE'S NUMBER: 14
   NODE'S TYPE IS:Q-SINGLE
   PRE-NODE'S NUMBER: 1250
   PRE-NODE'S TYPE  : 10
   SUCC-NODE'S NUMBER: 1535
   SUCC-NODE'S TYPE  : 10
--------------------------------------------------
                     MIN        MAX        MEAN        S.D
                  ---------  ---------  ----------  -------
IDLE TIME    :      53.04      73.56      62.73       4.457
--------------------------------------------------------------------

8  NODE'S NUMBER: 16
   NODE'S TYPE IS:Q-SINGLE
   PRE-NODE'S NUMBER: 1535
   PRE-NODE'S TYPE  : 10
   SUCC-NODE'S NUMBER: 1820
   SUCC-NODE'S TYPE  : 10
--------------------------------------------------
                     MIN        MAX        MEAN        S.D
                  ---------  ---------  ----------  -------
IDLE TIME    :      10.21      40.10      24.74       5.763
--------------------------------------------------------------------

9  NODE'S NUMBER: 18
   NODE'S TYPE IS:SINK
   PRE-NODE'S NUMBER: 1820
   PRE-NODE'S TYPE  : 10
   THE NUMBER OF UNITS= 1
--------------------------------------------------
                     MIN        MAX        MEAN        S.D
                  ---------  ---------  ----------  -------
RELEASING TIME:    219.86     235.78     227.42       3.055
--------------------------------------------------------------------
```

Figure (65)- Continued.

```
10 NODE'S NUMBER: 20
   NODE'S TYPE IS:Q-SINGLE
   PRE-NODE'S NUMBER: 1820
   PRE-NODE'S TYPE   : 10
   SUCC-NODE'S NUMBER: 2000
   SUCC-NODE'S TYPE  : 10
```

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	2.84	1.04	0.805

```
11 NODE'S NUMBER: 22
   NODE'S TYPE IS.SINK
   PRE-NODE'S NUMBER: 2000
   PRE-NODE'S TYPE   : 10
   THE NUMBER OF UNITS= 1
```

	MIN	MAX	MEAN	S.D
RELEASING TIME:	223.23	237.78	230.46	2.806

COPY OF SCHEDULE OF LABOUR RESOURCE CATEGORY: 15
****

SEQ	NODE NO	NODE TYPE	NO.OF UNITS	PARA TITLE	PARA TYPE	MIN	MAX	M-L MEAN	S.D	C-I
1	1085	ACT	1	STR-T E-DUR	 UNIF	122.28 8.00	130.02 10.00	126.30	1.676	0.00
2	1370	ACT	1	STR-T E-DUR	 UNIF	134.79 4.50	143.34 6.50	139.70	1.749	0.00
3	1655	ACT	1	STR-T E-DUR	 UNIF	154.21 5.50	164.64 8.00	159.69	1.805	0.00
4	1925	ACT	1	STR-T E-DUR	 CONS	161.67 2.00	171.98	166.63	2.021	0.00
5	10	SINK	1	REL-T		163.67	173.98	168.63	2.023	
6	1250	ACT	2	STR-T E-DUR	 UNIF	154.83 7.50	166.42 10.00	160.97	2.022	0.00
7	1535	ACT	2	STR-T E-DUR	 UNIF	193.77 5.00	208.58 8.00	201.03	2.568	0.00
8	1820	ACT	2	STR-T E-DUR	 UNIF	212.40 6.00	226.81 9.00	219.93	2.822	0.00
9	18	SINK	1	REL-T		219.86	235.78	227.42	3.055	
10	2000	ACT	1	STR-T E-DUR	 CONS	221.23 2.00	235.78	228.46	2.806	0.00
11	22	SINK	1	REL-T		223.23	237.78	230.46	2.806	

Figure (66)- Schedule For The Plumbing Crew (L-15) (first run).

COPY OF DETAILED REPORT ON LABOUR RESOURCE CATEGORY: 14
****

CATEGORY DESCRIPTION:ALUMINUM-W+D
THE NUMBER OF LQNODES= 8
UNIT RATE/TIME UNIT= 150

	MIN	MAX	MEAN	S.D
IDLE TIME :	48.33	97.51	67.14	9.946
IDLE TIME COST:	7249.75	14626.49	10071.18	1491.859

COPY OF DETAILED REPORT ON THE QNODES OF LABOUR RESOURCE CATEGORY: 14
****

1 NODE'S NUMBER: 2
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1330
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1375
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

2 NODE'S NUMBER: 4
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1375
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1560
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	23.23	37.56	30.02	2.507

Figure (67)- Detailed Report On Aluminum D+W Crew (L-14) (first run).

3 NODE'S NUMBER: 6
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1660
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 2060
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

4 NODE'S NUMBER: 8
NODE'S TYPE IS:SINK
PRE-NODE'S NUMBER: 2060
PRE-NODE'S TYPE : 10
THE NUMBER OF UNITS= 2

	MIN	MAX	MEAN	S.D
RELEASING TIME:	165.84	175.16	171.15	2.052

5 NODE'S NUMBER: 10
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1495
PRE-NODE'S TYPE : 12
SUCC-NODE'S NUMBER: 1540
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

6 NODE'S NUMBER: 11
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1540
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1825
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	17.92	59.95	37.12	9.044

7 NODE'S NUMBER: 14
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1825
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 2095
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

Figure (67)- Continued.

8 NODE'S NUMBER: 16
NODE'S TYPE IS:SINK
PRE-NODE'S NUMBER: 2095
PRE-NODE'S TYPE : 10
THE NUMBER OF UNITS= 3

	MIN	MAX	MEAN	S.D
RELEASING TIME:	227.18	241.43	234.49	3.099

COPY OF SCHEDULE OF LABOUR RESOURCE CATEGORY: 14
****

SEQ	NODE NO	NODE TYPE	NO.OF UNITS	PARA TITLE	PARA TYPE	MIN	MAX	M-L MEAN	S.D	C-I
1	1375	ACT	2	STR-T		134.79	143.34	139.70	1.749	0.00
				E-DUR	UNIF	4.00	6.00			
2	1660	ACT	2	STR-T		154.21	164.64	159.69	1.805	0.00
				E-DUR	UNIF	5.00	8.00			
3	2060	ACT	2	STR-T		161.08	170.25	166.31	1.934	0.66
				E-DUR	UNIF	4.00	6.00			
4	8	SINK	2	REL-T		165.84	175.16	171.15	2.052	
5	1540	ACT	3	STR-T		193.77	208.58	201.03	2.568	0.00
				E-DUR	UNIF	5.00	8.00			
6	1825	ACT	3	STR-T		212.40	226.81	219.33	2.822	0.00
				E-DUR	UNIF	7.00	10.00			
7	2095	ACT	3	STR-T		221.64	236.37	228.52	3.037	0.47
				E-DUR	UNIF	5.00	7.00			
8	16	SINK	3	REL-T		227.18	241.43	234.49	3.099	

Figure (68)- Schedule For Aluminum D+W Crew (L-14) (first run).

COPY OF DETAILED REPORT ON LABOUR RESOURCE CATEGORY: 10
****

CATEGORY DESCRIPTION:BLOCKLAYING-C
THE NUMBER OF LQNODES= 8
UNIT RATE/TIME UNIT= 600

	MIN	MAX	MEAN	S.D
IDLE TIME :	2.27	7.94	5.02	1.010
IDLE TIME COST:	1362.22	4766.43	3010.58	605.933

COPY OF DETAILED REPORT ON THE QNODES OF LABOUR RESOURCE CATEGORY: 10
****

1 NODE'S NUMBER: 2
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 700
PRE-NODE'S TYPE : 18
SUCC-NODE'S NUMBER: 1045
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

2 NODE'S NUMBER: 4
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1045
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1330
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

Figure (69)- Detailed Report On The Blocklaying Crew (L-10) (first run).

3 NODE'S NUMBER: 6
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1330
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1615
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	2.27	7.94	5.02	1.010

4 NODE'S NUMBER: 8
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1615
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 1900
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

5 NODE'S NUMBER: 10
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 1900
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 2050
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

6 NODE'S NUMBER: 12
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 2050
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 2310
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

7 NODE'S NUMBER: 14
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 2310
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 2315
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

Figure (69)- Continued.

8 NODE'S NUMBER: 16
NODE'S TYPE IS:SINK
PRE-NODE'S NUMBER: 2315
PRE-NODE'S TYPE : 10
THE NUMBER OF UNITS= 1

	MIN	MAX	MEAN	S.D
RELEASING TIME:	167.36	176.75	172.20	1.764

COPY OF SCHEDULE OF LABOUR RESOURCE CATEGORY: 10
****

SEQ	NODE NO	NODE TYPE	NO.OF UNITS	PARA TITLE	PARA TYPE	MIN	MAX	M-L MEAN	S.D	C-I
1	1045	ACT	1	STR-T		115.15	123.62	119.35	1.659	0.00
				E-DUR	NORM	6.00	8.00	7.00	0.330	
2	1330	ACT	1	STR-T		122.28	130.02	126.30	1.676	0.00
				E-DUR	NORM	12.00	15.00	13.50	0.500	
3	1615	ACT	1	STR-T		140.52	149.08	144.71	1.626	0.34
				E-DUR	NORM	13.00	17.00	15.00	0.660	
4	1900	ACT	1	STR-T		154.21	164.64	159.69	1.805	0.00
				E-DUR	UNIF	2.00	3.00			
5	2050	ACT	1	STR-T		156.86	166 96	162.19	1.746	0.66
				E-DUR	CONS	1.00				
6	2310	ACT	1	STR-T		157 86	167.96	163.19	1.747	0.00
				E-DUR	UNIF	4.00	5.00			
7	2315	ACT	1	STR-T		162.65	172.28	167.67	1.790	0.00
				E-DUR	UNIF	4.00	5.00			
8	16	SINK	1	REL-T		167.36	176.75	172.20	1.764	

Figure (70)- Schedule For The Blocklaying Crew (L-10) (first run).

```
                 MILESTONES & TERMINAL NODE REPORT.
                 **********************************

NODE'S NUMBER= 2                 NODE'S TYPE= 28            C-INDEX= 1
STARTING TIME= 1                 INITIAL COST= 10000
                     ------------------------------
NODE'S NUMBER= 60                NODE'S TYPE= 12            C-INDEX= 0
                     ------------------------------
NODE'S NUMBER= 150               NODE'S TYPE= 18            C-INDEX= 0
TIME CONSTRAINT= 16              PROB.OF.ACHIEVING IT= 0
COST CONSTRAINT= 80400           PROB.OF.ACHIEVING IT= .44
                     ------------------------------
NODE'S NUMBER= 220               NODE'S TYPE= 18            C-INDEX= 1
TIME CONSTRAINT= 32              PROB.OF.ACHIEVING IT= 1
COST CONSTRAINT= 40800           PROB.OF.ACHIEVING IT= .94
                     ------------------------------
NODE'S NUMBER= 352               NODE'S TYPE= 12            C-INDEX= 1
                     ------------------------------
NODE'S NUMBER= 521               NODE'S TYPE= 12            C-INDEX= 0
                     ------------------------------
NODE'S NUMBER= 530               NODE'S TYPE= 18            C-INDEX= 0
TIME CONSTRAINT= 99              PROB.OF.ACHIEVING IT= 1
COST CONSTRAINT= 476000          PROB.OF.ACHIEVING IT= 1
                     ------------------------------
NODE'S NUMBER= 700               NODE'S TYPE= 18            C-INDEX= 0
TIME CONSTRAINT= 131             PROB.OF.ACHIEVING IT= 1
COST CONSTRAINT= 213500          PROB.OF.ACHIEVING IT= 1
                     ------------------------------
NODE'S NUMBER= 870               NODE'S TYPE= 18            C-INDEX= 0
TIME CONSTRAINT= 163             PROB.OF.ACHIEVING IT= 1
COST CONSTRAINT= 211500          PROB.OF.ACHIEVING IT= 1
                     ------------------------------
NODE'S NUMBER= 1006              NODE'S TYPE= 12            C-INDEX= 0
                     ------------------------------
NODE'S NUMBER= 1020              NODE'S TYPE= 18            C-INDEX= 1
TIME CONSTRAINT= 197             PROB.OF.ACHIEVING IT= 1
COST CONSTRAINT= 37000           PROB.OF.ACHIEVING IT= 1
                     ------------------------------
NODE'S NUMBER= 1125              NODE'S TYPE= 12            C-INDEX= 0
                     ------------------------------
NODE'S NUMBER= 1210              NODE'S TYPE= 12            C-INDEX= 0
                     ------------------------------
NODE'S NUMBER= 1290              NODE'S TYPE= 12            C-INDEX= 0
                     ------------------------------
```

Figure (71)- Summary Report On Milestones And TERMINAL node (second run).

```
NODE'S NUMBER= 1320          NODE'S TYPE= 18              C-INDEX= 0
TIME CONSTRAINT= 218         PROB.OF.ACHIEVING IT= .89
COST CONSTRAINT= 313000      PROB.OF.ACHIEVING IT= 1
                  ----------------------------

NODE'S NUMBER= 1410          NODE'S TYPE= 12              C-INDEX= 0
                  ----------------------------

NODE'S NUMBER= 1495          NODE'S TYPE= 12              C-INDEX= 0
                  ----------------------------

NODE'S NUMBER= 1575          NODE'S TYPE= 12              C-INDEX= 0
                  ----------------------------

NODE'S NUMBER= 1605          NODE'S TYPE= 18              C-INDEX= 0
TIME CONSTRAINT= 227         PROB.OF.ACHIEVING IT= .98
COST CONSTRAINT= 308500      PROB.OF.ACHIEVING IT= 1
                  ----------------------------

NODE'S NUMBER= 1695          NODE'S TYPE= 12              C-INDEX= 0
                  ----------------------------

NODE'S NUMBER= 1780          NODE'S TYPE= 12              C-INDEX= 0
                  ----------------------------

NODE'S NUMBER= 1860          NODE'S TYPE= 12              C-INDEX= 0
                  ----------------------------

NODE'S NUMBER= 1890          NODE'S TYPE= 18              C-INDEX= 0
TIME CONSTRAINT= 235         PROB.OF.ACHIEVING IT= .87
COST CONSTRAINT= 296000      PROB.OF.ACHIEVING IT= .31
                  ----------------------------

NODE'S NUMBER= 1950          NODE'S TYPE= 12              C-INDEX= 0
                  ----------------------------

NODE'S NUMBER= 2030          NODE'S TYPE= 12              C-INDEX= 0
                  ----------------------------

NODE'S NUMBER= 2130          NODE'S TYPE= 12              C-INDEX= 0
                  ----------------------------

NODE'S NUMBER= 2155          NODE'S TYPE= 12              C-INDEX= 0
                  ----------------------------

NODE'S NUMBER= 2185          NODE'S TYPE= 18              C-INDEX= 1
TIME CONSTRAINT= 245         PROB.OF.ACHIEVING IT= .97
COST CONSTRAINT= 133500      PROB.OF.ACHIEVING IT= .83
                  ----------------------------

NODE'S NUMBER= 2235          NODE'S TYPE= 12              C-INDEX= 0
                  ----------------------------

NODE'S NUMBER= 2400          NODE'S TYPE= 18              C-INDEX= 0
TIME CONSTRAINT= 245         PROB.OF.ACHIEVING IT= 1
COST CONSTRAINT= 132500      PROB.OF.ACHIEVING IT= 0
                  ----------------------------
```

Figure (71)- Continued.

```
HARD COPY OF TERM NODE'S PARA DIST.
***********************************




        0.0   0.1   0.2   0.3   0.4   0.5   0.6   0.7   0.8   0.9   1.0
     MIN-I----I----I----I----I----I----I----I----I----I----I----I----I
  233.65-I*.......................................................0.020
  234.83-I........................................................0.010
  236.01-I**......................................................0.040
  237.19-I*****...................................................0.100
  238.37-I*****...................................................0.120
  239.55-I**********..............................................0.200
  240.73-I**********..............................................0.210
  241.91-I********................................................0.170
  243.09-I***.....................................................0.070
  244.27-I........................................................0.020
  245.45-I*.......................................................0.020
  246.63-I........................................................0.010
  247.81-I........................................................0.010
     MAX-I----I----I----I----I----I----I----I----I----I----I----I----I
     TN-TYPE   = 26             MIN   = 233.65      MODE VALUE= 240.73
     NO.OF.OBS= 100             MAX   = 247.81      MODE PROB =   0.210
     TIME-CONS= 245             MEAN  = 240.09      PEAR SKEW =   0.64
     TCI-INDEX=0.970            S.D   =   2.473     PEAR-COFF =   0.259
                                C.O.V=    0.010

                      (a)-PDF OF COPMLETION TIME.
                      ---------------------------
```

```
        0.0   0.1   0.2   0.3   0.4   0.5   0.6   0.7   0.8   0.9   1.0
     MIN-I----I----I----I----I----I----I----I----I----I----I----I----I
  233.06-I........................................................0.000
  234.24-I*.......................................................0.020
  235.42-I*.......................................................0.030
  236.60-I***.....................................................0.070
  237.78-I********................................................0.170
  238.96-I**************..........................................0.290
  240.14-I************************................................0.490
  241.32-I***********************************.....................0.700
  242.50-I*******************************************.............0.870
  243.68-I***********************************************.........0.940
  244.86-I************************************************........0.960
  246.04-I*************************************************.......0.980
  247.22-I*************************************************.......0.990
  248.40-I**************************************************......1.000
     MAX-I----I----I----I----I----I----I----I----I----I----I----I----I
     TN-TYPE   = 26             MIN   = 233.65      MODE VALUE= 240.73
     NO.OF.OBS= 100             MAX   = 247.81      MODE PROB =   0.210
     TIME-CONS= 245             MEAN  = 240.09      PEAR SKEW =   0.64
     TCI-INDEX=0.970            S.D   =   2.473     PEAR-COFF =   0.259
                                C.O.V=    0.010

                      (b)-CDF OF COMPLETION TIME.
                      ---------------------------
```

Figure (72)- (PDF) And (CDF) Of Project Completion Time (second run).

```
          0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
       MIN-I----I----I----I----I----I----I----I----I----I----I----I
2353310.50-I.................................................... 0.010
2356029.00-I*...................................................0.020
2358747.00-I*................................................... 0.030
2361465.50-I******.............................................. 0.130
2364183.50-I***.................................................0.060
2366902.00-I**********.......................................... 0.210
2369620.00-I**********.......................................... 0.210
2372338.50-I*******.............................................0.150
2375056.50-I****................................................ 0.090
2377775.00-I***.................................................0.070
2380493.00-I.......  ...........................................0.010
2383211.50-I....................................................0.000
2385929.00-I....................................................0.010
       MAX-I----I----I----I----I----I----I----I----I----I----I----I
       TN-TYPE   = 26         MIN   = 2353310.50      MODE VALUE= 2366902.00
       NO.OF.OBS= 100         MAX   = 2385928.20      MODE PROB =      0.210
       COST-CONS= 2490000     MEAN  = 2368716.00      PEAR SKEW =    1814.00
       CCI-INDEX=1.000        S.D   =    5837.698     PEAR-COFF =      0.311
                              C.O.V=        0.002

                              (c)-PDF OF NET COST.
                              --------------------
```

```
          0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
       MIN-I----I----I----I----I----I----I----I----I----I----I----I
...................................................................0.000
2351951.50-I.................................................... 0.010
2354869.80-I.................................................... 0.030
2357388.00-I*...................................................0.060
2360106.20-I***................................................. 0.190
2362824.50-I*********........................................... 0.250
2365542.80-I************........................................0.460
2368261.00-I***********************............................. 0.670
2370979.20-I*********************************...................0.820
2373697.50-I*****************************************........... 0.910
2376415.80-I*********************************************.......0.980
2379134.00-I*************************************************... 0.990
2381852.20-I*************************************************... 0.990
2384570.50-I**************************************************...1.000
2387287.20-I**************************************************
       MAX-I----I----I----I----I----I----I----I----I----I----I----I
       TN-TYPE   = 26         MIN   = 2353310.50      MODE VALUE= 2366902.00
       NO.OF.OBS= 100         MAX   = 2385928.20      MODE PROB =      0.210
       COST-CONS= 2490000     MEAN  = 2368716.00      PEAR SKEW =    1814.00
       CCI-INDEX=1.000        S.D   =    5837.698     PEAR-COFF =      0.311
                              C.O.V=        0.002

                              (d)-CDF OF NET COST.
                              --------------------
```

Figure (73)- (PDF) And (CDF) Of The Project Net Cost (second run).

```
            0.0   0.1   0.2   0.3   0.4   0.5   0.6   0.7   0.8   0.9   1.0
        MIN-I----I----I----I----I----I----I----I----I----I----I----I----I
   32975.03-I.................................................... 0.010
   33947.90-I.................................................... 0.010
   34920.76-I.................................................... 0.010
   35893.63-I**...................................................0.040
   36866.50-I*****................................................0.100
   37839.36-I*******..............................................0.150
   38812.23-I********.............................................0.160
   39785.10-I******.............................................. 0.130
   40757.97-I*********........................................... 0.190
   41730.83-I****................................................ 0.100
   42703.70-I****.................................................0.080
   43676.57-I.....................................................0.010
   44649.42-I.....................................................0.010
        MAX-I----I----I----I----I----I----I----I----I----I----I----I----I
        TN-TYPE   = 26          MIN   =    32975.03        MODE VALUE=   40757.97
        NO.OF.OBS= 100          MAX   =    44649.41        MODE PROB =      0.190
                                MEAN  =    39466.54        PEAR SKEW =    1291.42
                                S.D   =     2118.505       PEAR-COFF =      0.610
                                C.O.V=         0.054

                        (e)-PDF OF COST OF IDLE TIME OF RESOURCES.
                        -----------------------------------------
```

```
            0.0   0.1   0.2   0.3   0.4   0.5   0.6   0.7   0.8   0.9   1.0
        MIN-I----I----I----I----I----I----I----I----I----I----I----I----I
                                                                   ..0.000
   32488.60-I.................................................... 0.010
   33461.46-I.....................................................0.020
   34434.33-I*................................................... 0.030
   35407.20-I*................................................... 0.070
   36380.06-I***................................................. 0.170
   37352.93-I********.............................................0.320
   38325.80-I****************.....................................0.480
   39298.66-I************************............................ 0.610
   40271.53-I******************************.......................0.800
   41244.40-I****************************************.............0.900
   42217.27-I********************************************.........0.980
   43190.13-I*************************************************... 0.990
   44163.00-I*************************************************....1.000
   45135.85-I**************************************************
        MAX-I----I----I----I----I----I----I----I----I----I----I----I----I
        TN-TYPE   = 26          MIN   =    32975.03        MODE VALUE=   40757.97
        NO.OF.OBS= 100          MAX   =    44649.41        MODE PROB =      0.190
                                MEAN  =    39466.54        PEAR SKEW =    1291.42
                                S.D   =     2118.505       PEAR-COFF =      0.610
                                C.O.V=         0.054

                        (f)-CDF OF COST OF IDLE TIME OF RESOURCES
                        -----------------------------------------
```

Figure (74)- (PDF) And (CDF) Of Total Idle Time Cost Of Resources (second run).

```
                0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
           MIN-I----I----I----I----I----I----I----I----I----I----I----I
2390598.00-I................................................... 0.010
2393442.00-I*...................................................0.020
2396286.50-I**..................................................0.040
2399130.50-I****................................................0.080
2401975.00-I****................................................0.090
2404819.00-I*****...............................................0.100
2407663.50-I***********.........................................0.220
2410507.50-I*********.......................................... 0.190
2413352.00-I*****...............................................0.100
2416196.00-I***................................................ 0.080
2419040.50-I**..................................................0.040
2421884.50-I................................................... 0.020
2424728.50-I....................................................0.010
           MAX-I----I----I----I----I----I----I----I----I----I----I----I
           TN-TYPE  = 26        MIN  = 2390597.80     MODE VALUE= 2407663.50
           NO.OF.OBS= 100       MAX  = 2424728.00     MODE PROB =       0.220
           COST-CONS= 2490000   MEAN = 2408182.80     PEAR SKEW =      519.25
           CCI-INDEX=1.000      S.D  =    6636.278    PEAR-COFF =       0.078
                                C.O.V=       0.003

                                (g)-PDF OF TOTAL COST.
                                ----------------------
```

```
                0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
           MIN-I----I----I----I----I----I----I----I----I----I----I----I
                                                                0.000
2389175.80-I................................................... 0.010
2392020.00-I................................................... 0.030
2394864.20-I*.................................................. 0.070
2397708.50-I***................................................ 0.150
2400552.80-I*******.............................................0.240
2403397.00-I*************.......................................0.340
2406241.20-I******************..................................0.560
2409085.50-I*****************************...................... 0.750
2411929.80-I****************************************........... 0.850
2414774.00-I**********************************************..... 0.930
2417618.20-I**************************************************..0.970
2420462.50-I***************************************************.0.990
2423306.80-I****************************************************1.000
2426150.00-I****************************************************
           MAX-I----I----I----I----I----I----I----I----I----I----I----I
           TN-TYPE  = 26        MIN  = 2390597.80     MODE VALUE= 2407663.50
           NO.OF.OBS= 100       MAX  = 2424728.00     MODE PROB =       0.220
           COST-CONS= 2490000   MEAN = 2408182.80     PEAR SKEW =      519.25
           CCVI-INDEX=1.000     S.D  =    6636.278    PEAR-COFF =       0.078
                                C.O.V=       0.003

                                (h)-CDF OF TOTAL COST.
                                ----------------------
```

Figure (75)- (PDF) And (CDF) Of Project Total Cost (second run).

A LIST OF ADNODES IN THE DESCENDING ORDER OF CI.
****

SEQ	NODE'S NUMBER	NODE'S TYPE	C-INDEX
1	2	28	1
2	10	10	1
3	335	10	1
4	35	10	1
5	350	10	1
6	575	11	1
7	715	10	1
8	595	10	1
9	2185	18	1
10	615	10	1
11	880	10	1
12	635	10	1
13	895	11	1
14	165	10	1
15	180	10	1
16	190	10	1
17	200	10	1
18	210	10	1
19	220	18	1
20	235	10	1
21	305	10	1
22	255	10	1
23	735	10	1
24	275	10	1
25	745	11	1
26	285	11	1
27	765	10	1
28	420	11	1
29	315	10	1
30	785	10	1
31	545	10	1
32	340	11	1
33	565	10	1
34	352	12	1
35	2085	10	1
36	370	10	1
37	980	10	1
38	390	10	1
39	2075	10	1
40	410	10	1
41	890	10	1
42	450	10	1
43	645	11	1
44	920	10	1
45	464	10	1
46	460	10	1
47	950	11	1
48	2050	10	1
49	2095	10	1
50	470	11	1
51	1020	18	1
52	940	10	1
53	805	10	1
54	2115	10	1
55	905	10	1
56	315	11	1
57	2410	26	1
58	2060	10	0
59	365	10	0
60	30	10	0
61	490	11	0
62	465	11	0
63	60	12	0
64	325	10	0
65	15	10	0
66	610	10	0
67	115	10	0
68	90	10	0
69	150	18	0
70	640	11	0
71	590	10	0
72	660	11	0
73	665	11	0
74	110	[illegible]	0
75	[illegible]	[illegible]	[illegible]

Figure (76)- Project Activities In The Descending Order Of Their Criticality Index (second run).

SEQ	NODE'S NUMBER	NODE'S TYPE	C-INDEX
76	700	18	0
77	710	10	0
78	240	10	0
79	85	10	0
80	260	10	0
81	505	10	0
82	630	10	0
83	521	12	0
84	525	10	0
85	530	18	0
86	540	10	0
87	800	10	0
88	680	10	0
89	810	11	0
90	570	11	0
91	830	11	0
92	835	11	0
93	850	10	0
94	385	10	0
95	870	18	0
96	405	10	0
97	120	10	0
98	415	11	0
99	435	10	0
100	915	10	0
101	445	10	0
102	935	10	0
103	685	10	0
104	463	10	0
105	955	11	0
106	960	10	0
107	975	10	0
108	485	11	0
109	1006	12	0
110	280	10	0
111	510	10	0
112	290	11	0
113	1075	10	0
114	1080	10	0
115	1085	10	0
116	560	10	0
117	1095	10	0
118	1125	12	0
119	1150	10	0
120	1155	10	0
121	1160	10	0
122	1180	10	0
123	1185	10	0
124	1190	10	0
125	1210	12	0
126	1240	10	0
127	1245	10	0
128	1250	10	0
129	1255	10	0
130	1260	10	0
131	1290	12	0
132	1310	10	0
133	1315	10	0
134	1320	18	0
135	1330	10	0
136	1360	10	0
137	1365	10	0
138	1010	10	0
139	1375	10	0
140	1045	10	0
141	1410	12	0
142	780	10	0
143	1440	10	0
144	1445	10	0
145	1465	10	0
146	1470	10	0
147	1475	10	0
148	1495	12	0
149	1525	10	0
150	1530	10	0
151	1535	10	0
152	1540	10	0

Figure (76)- Continued.

SEQ	NODE'S NUMBER	NODE'S TYPE	C-INDEX
153	1545	10	0
154	1575	12	0
155	1595	10	0
156	1600	10	0
157	1605	18	0
158	1615	10	0
159	1645	10	0
160	1650	10	0
161	1655	10	0
162	1660	10	0
163	1665	10	0
164	1695	12	0
165	1720	10	0
166	1725	10	0
167	1730	10	0
168	1750	10	0
169	1755	10	0
170	1760	10	0
171	1780	12	0
172	1810	10	0
173	1815	10	0
174	1820	10	0
175	1825	10	0
176	1830	10	0
177	1860	12	0
178	1880	10	0
179	1885	10	0
180	1890	18	0
181	1900	10	0
182	1920	10	0
183	1925	10	0
184	1930	10	0
185	1950	12	0
186	1960	10	0
187	1970	10	0
188	1995	10	0
189	2000	10	0
190	2005	10	0
191	2010	10	0
192	2030	12	0
193	2040	10	0
194	730	10	0
195	1370	10	0
196	740	11	0
197	1380	10	0
198	750	10	0
199	1435	10	0
200	2120	10	0
201	2130	12	0
202	2136	10	0
203	2138	10	0
204	2144	10	0
205	2146	10	0
206	2155	12	0
207	2160	10	0
208	2170	10	0
209	855	10	0
210	2195	10	0
211	2205	10	0
212	2215	10	0
213	2225	10	0
214	2235	12	0
215	2250	10	0
216	2255	10	0
217	2257	10	0
218	2270	10	0
219	2275	10	0
220	2290	10	0
221	2295	10	0
222	2310	10	0
223	2315	10	0
224	2340	10	0
225	2345	10	0
226	2350	10	0
227	2355	10	0
228	2380	10	0
229	2385	10	0
230	2400	18	0
231	1060	10	

Figure (76)- Continued.

COPY OF SUMMARY REPORT ON LABOUR RESOURCE.
****

THE NUMBER OF LABOUR RESOURCE CATEGORIES= 21

CATEGORY NO	NO.OF.QNODES
1	3
2	2
3	2
4	6
5	4
6	5
7	13
8	5
9	4
10	8
11	9
12	10
13	8
14	8
15	11
16	7
17	24
18	15
19	5
20	7
21	9

SEQ	CATEGORY NUMBER	NO.OF NODES	UNIT RATE /TIME UNIT	IDLE TIME MEAN	IDLE TIME S.D	MEAN VALUE I.T.(COST)
1	17	24	150	87.51	8.918	13126.832
2	18	15	150	50.39	5.463	7558.515
3	14	8	150	67.14	9.946	10071.181
4	11	9	300	0.00	0.000	0.000
5	4	6	150	0.00	0.000	0.000
6	19	5	300	0.00	0.000	0.000
7	6	5	1000	0.00	0.000	0.000
8	3	2	250	0.00	0.000	0.000
9	5	4	550	0.00	0.000	0.000
10	10	8	900	0.00	0.000	0.000
11	1	3	250	0.00	0.000	0.000
12	2	2	350	0.00	0.000	0.000
13	13	8	200	0.00	0.000	0.000
14	7	13	1200	0.00	0.000	0.000
15	15	11	150	0.00	0.000	0.000
16	16	7	400	0.00	0.000	0.000
17	12	10	200	0.00	0.000	0.000
18	8	5	300	0.00	0.000	0.000
19	9	4	300	0.00	0.000	0.000
20	20	7	150	0.00	0.000	0.000
21	21	9	50	0.00	0.000	0.000

Figure (77)- Summary Report On Labour Resources (second run).

COPY OF SUMMARY REPORT ON MACHINARY RESOURCE.
****

THE NUMBER OF MACHINARY RESOURCE CATEGORIES= 7

CATEGORY NO	NO.OF.QNODES
1	4
2	5
3	4
4	2
5	2
6	18
7	18

THE START OF THE LIST.

SEQ	CATEGORY NUMBER	NO.OF NODES	UNIT RATE /TIME UNIT	IDLE TIME MEAN	IDLE TIME S.D	MEAN VALUE I.T.(COST)
1	1	4	2600	0.00	0.000	0.000
2	2	5	1200	0.00	0.000	0.000
3	3	4	1600	0.00	0.000	0.000
4	4	2	1900	0.00	0.000	0.000
5	5	2	2000	0.00	0.000	0.000
6	6	18	1200	0.00	0.000	0.000
7	7	18	2100	0.00	0.000	0.000

Figure (78)- Summary Report On Machinery Resources (second run).

COPY OF DETAILED REPORT ON MACHINARY RESOURCE CATEGORY: 1
****

CATEGORY DESCRIPTION:EXCAV-CREW(SITE & BU
THE NUMBER OF MQNODES= 4
UNIT RATE/TIME UNIT= 2600

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000
IDLE TIME COST:	0.00	0.00	0.00	0.000

COPY OF DETAILED REPORT ON THE QNODES OF MACHINARY RESOURCE CATEGORY: 1
****

1 NODE'S NUMBER: 2
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 2
PRE-NODE'S TYPE : 28
SUCC-NODE'S NUMBER: 15
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

2 NODE'S NUMBER: 4
NODE'S TYPE IS:Q-SINGLE
PRE-NODE'S NUMBER: 15
PRE-NODE'S TYPE : 10
SUCC-NODE'S NUMBER: 40
SUCC-NODE'S TYPE : 10

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

Figure (79)- Detailed Report On Site Excavation Crew (second run).

```
3  NODE'S NUMBER: 6
   NODE'S TYPE IS:Q-SINGLE
   PRE-NODE'S NUMBER: 40
   PRE-NODE'S TYPE  : 10
   SUCC-NODE'S NUMBER: 165
   SUCC-NODE'S TYPE  : 10
```

	MIN	MAX	MEAN	S.D
IDLE TIME :	0.00	0.00	0.00	0.000

```
4  NODE'S NUMBER: 8
   NODE'S TYPE IS:SINK
   PRE-NODE'S NUMBER: 165
   PRE-NODE'S TYPE  : 10
   THE NUMBER OF UNITS= 1
```

	MIN	MAX	MEAN	S.D
RELEASING TIME:	16.35	19.81	18.30	0.753

COPY OF SCHEDULE OF MACHINARY RESOURCE CATEGORY: 1
****

SEQ	NODE NO	NODE TYPE	NO.OF UNITS	PARA TITLE	PARA TYPE	MIN	MAX	M-L MEAN	S.D	C-I
1	15	ACT	1	STR-T		1.00	1.00	1.00	0.000	0.00
				E-DUR	CONS	1.00				
2	40	ACT	1	STR-T		2.00	2.00	2.00	0.000	0.00
				E-DUR	BETA	6.00	9.00	7.00		
3	165	ACT	1	STR-T		8.14	10.44	9.22	0.505	1.00
				E-DUR	BETA	8.00	11.00	9.00		
4	8	SINK	1	REL-T		16.35	19.81	18.30	0.753	

Figure (80)- Schedule For The Site Excavation Crew (second run).

A COPY OF ADNODES DETAILED REPORT.

THE MAIN NETWORK HAS: 231 NODES.

NODE'S LABEL:d- 2 NODE'S TYPE: 28 C-INDEX= 1
NODE'S DESCRIPTION:START

NO	NO.OF.SUCC-N: 3 LABEL	NO.OF.SUCC-RN: 2 LABEL	NO.UNI
1	s- 4	l 1 - 2	1
2	s- 6	m 1 - 2	1
3	f- 8		

STARTING TIME= 1 INITIAL COST= 10000

NODE'S LABEL:a- 10 NODE'S TYPE: 10 C-INDEX= 1
NODE'S DESCRIPTION:SURVEY & S-LAYOUT

NO	NO.OF.PRE-N: 1 LABEL	NO.OF.SUCC-N: 2 LABEL	NO.OF.PRE-RN: 1 LABEL	NO.UNI	NO.OF.SUCC-RN: 1 LABEL	NO.UNI
1	s- 4	s- 20	l 1 - 2	1	l 1 - 4	1
2		s- 25				

FIXED COST= 100 VARIABLE COST= 250

	TYPE	MIN	MAX	M-MEAN	S.D
STARTING TIME:	-	1.00	1.00	1.00	0.000
ESTIMATED DUR:	CONSTANT	1			

NODE'S LABEL:a- 15 NODE'S TYPE: 10 C-INDEX= 0
NODE'S DESCRIPTION:CLEAR SITE

NO	NO.OF.PRE-N: 1 LABEL	NO.OF.SUCC-N: 1 LABEL	NO.OF.PRE-RN: 1 LABEL	NO.UNI	NO.OF.SUCC-RN: 1 LABEL	NO.UNI
1	s- 6	s- 30	m 1 - 2	1	m 1 - 4	1

FIXED COST= 0 VARIABLE COST= 2600

	TYPE	MIN	MAX	M-MEAN	S.D
STARTING TIME:	-	1.00	1.00	1.00	0.000
ESTIMATED DUR:	CONSTANT	1			

Figure (81)- Schedule For Sub-Network (A) And (B) (second run).

```
NODE'S LABEL:a- 35        NODE'S TYPE: 10       C-INDEX= 1
NODE'S DESCRIPTION:BUILDING LAYOUT
--------------------------------------------------------------------------------
       NO.OF.PRE-N: 1   NO.OF.SUCC-N: 2     NO.OF.PRE-RN: 1   NO.OF.SUCC-RN: 1
       --------------   --------------     ---------------   ----------------
 NO          LABEL            LABEL          LABEL    NO.UNI   LABEL      NO.UNI
----         -----            -----          -----    ------   -----      ------
  1          s- 20            s- 45          1 1 - 4      1    1 1 - 6        1

  2                           s- 50

FIXED COST= 100              VARIABLE COST= 250
--------------------------------------------------------------------------------
                    TYPE                MIN        MAX        M-MEAN     S.D
                    ----                ---        ---        ------     ---
STARTING TIME:       -                  2.00       2.00       2.00       0.000
ESTIMATED DUR:   CONSTANT               1
********************************************************************************

NODE'S LABEL:a- 40        NODE'S TYPE: 10       C-INDEX= 0
NODE'S DESCRIPTION:ROUGH-GRADE
--------------------------------------------------------------------------------
       NO.OF.PRE-N: 2   NO.OF.SUCC-N: 1     NO.OF.PRE-RN: 1   NO.OF.SUCC-RN: 1
       --------------   --------------     ---------------   ----------------
 NO          LABEL            LABEL          LABEL    NO.UNI   LABEL      NO.UNI
----         -----            -----          -----    ------   -----      ------
  1          s- 25            s- 55          m 1 - 4      1    m 1 - 6        1

  2          s- 30

FIXED COST= 0                VARIABLE COST= 2600
--------------------------------------------------------------------------------
                    TYPE                MIN        MAX        M-MEAN     S.D
                    ----                ---        ---        ------     ---
STARTING TIME:       -                  2.00       2.00       2.00       0.000
ESTIMATED DUR:   BETA(PERT)             6          9          7
********************************************************************************

NODE'S LABEL:d- 60        NODE'S TYPE: 12       C-INDEX= 0
NODE'S DESCRIPTION:END-(SURV+GRAD)
--------------------------------------------------------------------------------
       NO.OF.PRE-N: 2   NO.OF.SUCC-N: 3     NO.OF.SUCC-RN: 2
       --------------   --------------     ----------------
 NO          LABEL            LABEL          LABEL   NO.UNI
----         -----            -----          -----   ------
  1          s- 50            s- 65          1 2 - 2    1
  2          s- 55            s- 70          1 21 - 2   3
  3                           s- 75
--------------------------------------------------------------------------------
                    TYPE                MIN        MAX        M-MEAN     S.D
                    ----                ---        ---        ------     ---
STARTING TIME:       -                  8.14       10.44      9.22       0.505
********************************************************************************

NODE'S LABEL:a- 80        NODE'S TYPE: 10       C-INDEX= 0
NODE'S DESCRIPTION:T.C-BASE
--------------------------------------------------------------------------------
       NO.OF.PRE-N: 1   NO.OF.SUCC-N: 1     NO.OF.PRE-RN: 1   NO.OF.SUCC-RN: 2
       --------------   --------------     ---------------   ----------------
 NO          LABEL            LABEL          LABEL    NO.UNI   LABEL      NO.UNI
----         -----            -----          -----    ------   -----      ------
  1          s- 65            s- 95          1 21 - 2     3    1 21 - 21      3
  .                                                            1 5 - 5        1
  2

FIXED COST= 3000             VARIABLE COST= 150
--------------------------------------------------------------------------------
                    TYPE                MIN        MAX        M-MEAN     S.D
                    ----                ---        ---        ------     ---
STARTING TIME:       -                  8.14       10.44      9.22       0.505
ESTIMATED DUR:   CONSTANT               1
********************************************************************************
```

Figure (81)- Continued.

NODE'S LABEL:a- 85 NODE'S TYPE: 10 C-INDEX= 0
NODE'S DESCRIPTION:SETUP ACC

	NO.OF.PRE-N: 1	NO.OF.SUCC-N: 1	NO.OF.PRE-RN: 1		NO.OF.SUCC-RN: 2	
NO	LABEL	LABEL	LABEL	NO.UNI	LABEL	NO.UNI
1	s- 70	s- 100	1 2 - 2	1	1 2 - 2	1
2					1 3 - 3	1

FIXED COST= 20000 VARIABLE COST= 350

	TYPE	MIN	MAX	M-MEAN	S.D
STARTING TIME:	-	8.14	10.44	9.22	0.505
ESTIMATED DUR:	UNIFORM	6	8		

****

NODE'S LABEL:a- 90 NODE'S TYPE: 10 C-INDEX= 0
NODE'S DESCRIPTION:EXCAV-T.S

	NO.OF.PRE-N: 1	NO.OF.SUCC-N: 1	NO.OF.PRE-RN: 1		NO.OF.SUCC-RN: 2	
NO	LABEL	LABEL	LABEL	NO.UNI	LABEL	NO.UNI
1	s- 75	s- 105	1 21 - 4	3	1 21 - 21	3
2					1 4 - 4	1

FIXED COST= 0 VARIABLE COST= 150

	TYPE	MIN	MAX	M-MEAN	S.D
STARTING TIME:	-	9.14	11.44	10.22	0.505
ESTIMATED DUR:	CONSTANT	2			

****

NODE'S LABEL:a- 110 NODE'S TYPE: 10 C-INDEX= 0
NODE'S DESCRIPTION:INSTALL-T.C

	NO.OF.PRE-N: 1	NO.OF.SUCC-N: 3	NO.OF.PRE-RN: 1		NO.OF.SUCC-RN: 1	
NO	LABEL	LABEL	LABEL	NO.UNI	LABEL	NO.UNI
1	s- 95	s- 135	1 5 - 2	1	1 5 - 5	1
2		f- 140				
3		s- 145				

FIXED COST= 200 VARIABLE COST= 550

	TYPE	MIN	MAX	M-MEAN	S.D
STARTING TIME:	-	9.14	11.44	10.22	0.505
ESTIMATED DUR:	UNIFORM	6	8		

****

NODE'S LABEL:a- 115 NODE'S TYPE: 10 C-INDEX= 0
NODE'S DESCRIPTION:E.W-T S

	NO.OF.PRE-N: 1	NO.OF.SUCC-N: 1	NO.OF.PRE-RN: 1		NO.OF.SUCC-RN: 1	
NO	LABEL	LABEL	LABEL	NO UNI	LABEL	NO.UNI
1	s- 100	s- 125	1 3 - 2	1	1 3 - 3	1

FIXED COST= 6000 VARIABLE COST= 250

	TYPE	MIN	MAX	M-MEAN	S.D
STARTING TIME:	-	14.45	17.98	16.16	0.882
ESTIMATED DUR:	CONSTANT	3			

****

Figure (81)- Continued.

```
NODE'S LABEL:a- 120      NODE'S TYPE: 10      C-INDEX= 0
NODE'S DESCRIPTION:PLUMBING-T.S
--------------------------------------------------------------------------------
      NO.OF.PRE-N: 1  NO.OF.SUCC-N: 1   NO.OF.PRE-RN: 1  NO.OF.SUCC-RN: 1
      -------------   --------------   --------------   ---------------
 NO        LABEL            LABEL         LABEL    NO.UNI  LABEL     NO.UNI
----       -----            -----         -----    ------  -----     ------
  1        s- 105           s- 130        1 4 - 2     1    1 4 - 4      3

FIXED COST= 7500               VARIABLE COST= 150
--------------------------------------------------------------------------------
                      TYPE             MIN        MAX        M-MEAN     S.D
                      ----             ---        ---        ------     ---
STARTING TIME:         -               11.14      13.44      12.22      0.505
ESTIMATED DUR:     UNIFORM             6          8
********************************************************************************

NODE'S LABEL:d- 150      NODE'S TYPE: 18      C-INDEX= 0
NODE'S DESCRIPTION:END-(SITE SETUP)
--------------------------------------------------------------------------------
         NO.OF.PRE-N: 4    NO.OF.SUCC-N: 2     NO.OF.SUCC-RN: 0
         -------------     --------------     ---------------
 NO          LABEL               LABEL           LABEL  NO.UNI
----         -----               -----           -----  ------
  1          f- 8                f- 155
  2          s- 125              f- 160
  3          s- 130
  4          s- 145
--------------------------------------------------------------------------------
                      TYPE             MIN        MAX        M-MEAN     S.D
                      ----             ---        ---        ------     ---
STARTING TIME:         -               17.77      21.27      19.54      0.745
TIME CONSTRAINT= 16              PROB.OF ACHIEVING IT= 0
COST CONSTRAINT= 80400           PROB.OF ACHIEVING IT= .44
********************************************************************************

NODE'S LABEL:a- 165      NODE'S TYPE: 10      C-INDEX= 1
NODE'S DESCRIPTION:REDUCE LEVEL
--------------------------------------------------------------------------------
      NO.OF.PRE-N: 1  NO.OF.SUCC-N: 2   NO.OF.PRE-RN: 1  NO.OF.SUCC-RN: 2
      -------------   --------------   --------------   ---------------
 NO        LABEL            LABEL         LABEL    NO.UNI  LABEL     NO.UNI
----       -----            -----         -----    ------  -----     ------
  1        s- 45            s- 170        m 1 - 6     1    m 1 - 1      1

  2                         s- 175                         m 2 - 2      1

FIXED COST= 0                  VARIABLE COST= 2600
--------------------------------------------------------------------------------
                      TYPE             MIN        MAX        M-MEAN     S.D
                      ----             ---        ---        ------     ---
STARTING TIME:         -               8.14       10.44      9.22       0.505
ESTIMATED DUR:   BETA(PERT)            8          11         9
********************************************************************************

NODE'S LABEL:a- 180      NODE'S TYPE: 10      C-INDEX= 1
NODE'S DESCRIPTION:EXCAV-INT-D
--------------------------------------------------------------------------------
      NO.OF.PRE-N: 1  NO.OF.SUCC-N: 1   NO.OF.PRE-RN: 1  NO.OF.SUCC-RN: 1
      -------------   --------------   --------------   ---------------
 NO        LABEL            LABEL         LABEL    NO.UNI  LABEL     NO.UNI
----       -----            -----         -----    ------  -----     ------
  1        s- 170           s- 185        m 2 - 2     1    m 2 - 2      1

FIXED COST= 0                  VARIABLE COST= 1200
--------------------------------------------------------------------------------
                      TYPE             MIN        MAX        M-MEAN     S.D
                      ----             ---        ---        ------     ---
STARTING TIME:         -               16.35      19.81      18.30      0.753
ESTIMATED DUR:    TRIANGLE             1          2          1.5
********************************************************************************
```

Figure (81)- Continued.

```
NODE'S LABEL:a- 190     NODE'S TYPE: 10      C-INDEX= 1
NODE'S DESCRIPTION:BEDDING-INT-D
------------------------------------------------------------------------
      NO.OF.PRE-N: 1  NO.OF.SUCC-N: 1    NO.OF.PRE-RN: 1  NO.OF.SUCC-RN: 1
      --------------  ---------------    ---------------  ----------------
 NO        LABEL           LABEL         LABEL    NO.UNI  LABEL     NO.UNI
----       -----           -----         -----    ------  -----     ------
 1         s- 185          s- 195        1 4 - 4       3  1 4 - 4        3

FIXED COST= 350             VARIABLE COST= 450
------------------------------------------------------------------------
                    TYPE             MIN        MAX       M-MEAN    S.D
                    ----             ---        ---       ------    ---
STARTING TIME:       -              17.98      21.34      19.88     0.742
ESTIMATED DUR:   CONSTANT            1
************************************************************************

NODE'S LABEL:a- 200     NODE'S TYPE: 10      C-INDEX= 1
NODE'S DESCRIPTION:PIPLAY-INT-D
------------------------------------------------------------------------
      NO.OF.PRE-N: 1  NO.OF.SUCC-N: 1    NO.OF.PRE-RN: 1  NO.OF.SUCC-RN: 2
      --------------  ---------------    ---------------  ----------------
 NO        LABEL           LABEL         LABEL    NO.UNI  LABEL     NO.UNI
----       -----           -----         -----    ------  -----     ------
 1         s- 195          s- 205        1 4 - 6       3  1 4 - 4        3

 2                                                        m 3 - 3        1

FIXED COST= 8200            VARIABLE COST= 450
------------------------------------------------------------------------
                    TYPE             MIN        MAX       M-MEAN    S.D
                    ----             ---        ---       ------    ---
STARTING TIME:       -              18.98      22.34      20.88     0.742
ESTIMATED DUR:   UNIFORM             1.5        2
************************************************************************

NODE'S LABEL:a- 210     NODE'S TYPE: 10      C-INDEX= 1
NODE'S DESCRIPTION:BACKFILL-INT-D
------------------------------------------------------------------------
      NO.OF.PRE-N: 1  NO.OF.SUCC-N: 1    NO.OF.PRE-RN: 1  NO.OF.SUCC-RN: 1
      --------------  ---------------    ---------------  ----------------
 NO        LABEL           LABEL         LABEL    NO.UNI  LABEL     NO.UNI
----       -----           -----         -----    ------  -----     ------
 1         s- 205          s- 215        m 3 - 2       1  m 3 - 3        1

FIXED COST= 1000            VARIABLE COST= 1600
------------------------------------------------------------------------
                    TYPE             MIN        MAX       M-MEAN    S.D
                    ----             ---        ---       ------    ---
STARTING TIME:       -              20.79      24.18      22.64     0.771
ESTIMATED DUR:   CONSTANT            1
************************************************************************

NODE'S LABEL:d- 220     NODE'S TYPE: 18      C-INDEX= 1
NODE'S DESCRIPTION:END-(B+INT-D-EXCAV)
------------------------------------------------------------------------
      NO.OF.PRE-N: 2  NO.OF.SUCC-N: 3    NO.OF.SUCC-RN: 1
      --------------  ---------------    ----------------
 NO        LABEL           LABEL         LABEL  NO.UNI
----       -----           -----         -----  ------
 1         s- 135          f- 155        1 21 - 8  10
 2         s- 215          s- 225
 3                         s- 230
------------------------------------------------------------------------
                    TYPE             MIN        MAX       M-MEAN    S.D
                    ----             ---        ---       ------    ---
STARTING TIME:       -              21.79      25.18      23.64     0.771
TIME CONSTRAINT= 32             PROB.OF.ACHIEVING IT= 1
COST CONSTRAINT= 40800          PROB.OF.ACHIEVING IT= .94
************************************************************************
```

Figure (81)- Continued.

```
COPY OF SPACE ONODES DATA.
***************************

NODE'S NUMBER: 4                          NODE'S TYPE: 3
NODE'S DESCRIPTION:S-READY-SURVEYING
---------------------------------------------------------------------
PRE-NODE'S NUMBER: 3                      SUCC-NODE'S NUMBER: 10
                              MIN          MAX          MEAN         S.D
                              -------      -------      ------       -------
WAITING TIME:                 0.000        0.000        0.000        0.0000
*********************************************************************

NODE'S NUMBER: 6                          NODE'S TYPE: 4
NODE'S DESCRIPTION:S-READY-CLEARING
---------------------------------------------------------------------
PRE-NODE'S NUMBER: 3                      SUCC-NODE'S NUMBER: 15
                              MIN          MAX          MEAN         S.D
                              -------      -------      ------       -------
WAITING TIME:                 0.000        0.000        0.000        0.0000
*********************************************************************

NODE'S NUMBER: 8                          NODE'S TYPE: 1
NODE'S DESCRIPTION:OVERH-COST(S-SETUP)
---------------------------------------------------------------------
PRE-NODE'S NUMBER: 3                      SUCC-NODE'S NUMBER: 150
COST/TIME UNIT= 200
                              MIN          MAX          MEAN         S.D
                              -------      -------      ------       -------
COST PARAMETER:               3354.951     4053.475     3707.531     148.933
*********************************************************************

NODE'S NUMBER: 20                         NODE'S TYPE: 3
NODE'S DESCRIPTION:B-ZONE-READY(LAYOUT)
---------------------------------------------------------------------
PRE-NODE'S NUMBER: 10                     SUCC-NODE'S NUMBER: 35
                              MIN          MAX          MEAN         S.D
                              -------      -------      ------       -------
WAITING TIME:                 0.000        0.000        0.000        0.0000
*********************************************************************

NODE'S NUMBER: 25                         NODE'S TYPE: 4
NODE'S DESCRIPTION:S-READY(ROUGH-GRADE)
---------------------------------------------------------------------
PRE-NODE'S NUMBER: 10                     SUCC-NODE'S NUMBER: 40
                              MIN          MAX          MEAN         S.D
                              -------      -------      ------       -------
WAITING TIME:                 0.000        0.000        0.000        0.0000
*********************************************************************

NODE'S NUMBER: 30                         NODE'S TYPE: 4
NODE'S DESCRIPTION:S-[illegible]ARED(S-GRADE)
---------------------------------------------------------------------
PRE-NODE'S NUMBER: 15                     SUCC-NODE'S NUMBER: 40
                              MIN          MAX          MEAN         S.D
                              -------      -------      ------       -------
WAITING TIME:                 0.000        0.000        0.000        0.0000
*********************************************************************
```

Figure (82)-Detailed Report On S.Q.nodes Of Sub-Network (A And B)(second run).

NODE'S NUMBER: 45 NODE'S TYPE: 4

NODE'S DESCRIPTION:B-ZONE-READY(RED-LCV

PRE-NODE'S NUMBER: 35 SUCC-NODE'S NUMBER: 165

	MIN	MAX	MEAN	S.D
WAITING TIME:	5.176	7.443	6.215	0.5050

****

NODE'S NUMBER: 50 NODE'S TYPE: 3

NODE'S DESCRIPTION:B-LAYOUT FINISHED

PRE-NODE'S NUMBER: 35 SUCC-NODE'S NUMBER: 60

	MIN	MAX	MEAN	S.D
WAITING TIME:	5.136	7.443	6.215	0.5050

****

NODE'S NUMBER: 55 NODE'S TYPE: 4

NODE'S DESCRIPTION:S-R-GRADE FINISHED

PRE-NODE'S NUMBER: 40 SUCC-NODE'S NUMBER: 60

	MIN	MAX	MEAN	S.D
WAITING TIME:	0.000	0.000	0.000	0.0000

****

NODE'S NUMBER: 65 NODE'S TYPE: 4

NODE'S DESCRIPTION:S-R-(T.C-BASE)

PRE-NODE'S NUMBER: 60 SUCC-NODE'S NUMBER: 80

	MIN	MAX	MEAN	S.D
WAITING TIME:	0.000	0.000	0.000	0.0000

****

NODE'S NUMBER: 70 NODE'S TYPE: 3

NODE'S DESCRIPTION:S-R-(ACC-SETUP)

PRE-NODE'S NUMBER: 60 SUCC-NODE'S NUMBER: 85

	MIN	MAX	MEAN	S.D
WAITING TIME:	0.000	0.000	0.000	0.0000

****

NODE'S NUMBER: 75 NODE'S TYPE: 3

NODE'S DESCRIPTION:S-READY(T.S-E(CAV)

PRE-NODE'S NUMBER: 50 SUCC-NODE'S NUMBER: 90

	MIN	MAX	MEAN	S.D
WAITING TIME:	1.000	1.000	1.000	0.0000

****

NODE'S NUMBER: 95 NODE'S TYPE: 4

NODE'S DESCRIPTION:BASE-READY T.C-INSTA

PRE-NODE'S NUMBER: 30 SUCC-NODE'S NUMBER: 110

	MIN	MAX	MEAN	S.D
WAITING TIME:	0.000	0.000	0.000	0.0000

****

Figure (82)- Continued.

```
NODE'S NUMBER: 100                       NODE'S TYPE: 4
NODE'S DESCRIPTION:S-READY(E.W-T.S)
----------------------------------------------------------------------
PRE-NODE'S NUMBER: 95                    SUCC-NODE'S NUMBER: 115
                          MIN            MAX          MEAN          S.D
                        -------        -------       ------       -------
WAITING TIME:            0.000          0.000         0.000        0.0000
**********************************************************************

NODE'S NUMBER: 105                       NODE'S TYPE: 4
NODE'S DESCRIPTION:EXCAV READY(PLUMB-T.
----------------------------------------------------------------------
PRE-NODE'S NUMBER: [illegible]           SUCC-NODE'S NUMBER: 120
                          MIN            MAX          MEAN          S.D
                        -------        -------       ------       -------
WAITING TIME:            0.000          0.000         0.000        0.0000
**********************************************************************

NODE'S NUMBER: 125                       NODE'S TYPE: 4
NODE'S DESCRIPTION:E.W-T.S FINISHED
----------------------------------------------------------------------
PRE-NODE'S NUMBER: 115                   SUCC-NODE'S NUMBER: 150
                          MIN            MAX          MEAN          S.D
                        -------        -------       ------       -------
WAITING TIME:        [illegible]     [illegible]      0.378        0.4726
**********************************************************************

NODE'S NUMBER: 130                       NODE'S TYPE: 4
NODE'S DESCRIPTION:PLUMB-[illegible] FINISHED
----------------------------------------------------------------------
PRE-NODE'S NUMBER: [illegible]           SUCC-NODE'S NUMBER: 150
                          MIN            MAX          MEAN          S.D
                        -------        -------       ------       -------
WAITING TIME:        [illegible]        1.696         0.284        0.4559
**********************************************************************

NODE'S NUMBER: 135                       NODE'S TYPE: 3
NODE'S DESCRIPTION:[illegible] ROAD([illegible] USE)
----------------------------------------------------------------------
PRE-NODE'S NUMBER: 110                   SUCC-NODE'S NUMBER: 220
                          MIN            MAX          MEAN          S.D
                        -------        -------       ------       -------
WAITING TIME:        [illegible]        8.406         6.349        0.7826
**********************************************************************

NODE'S NUMBER: 140                       NODE'S TYPE: 1
NODE'S DESCRIPTION:[illegible] OPERATIONAL COST
----------------------------------------------------------------------
PRE-NODE'S NUMBER: 110                   SUCC-NODE'S NUMBER: 1006
COST/TIME UNIT= 500
                          MIN            MAX          MEAN          S.D
                        -------        -------       ------       -------
COST PARAMETER:      [illegible]      55659.988     53722.250     792.767
**********************************************************************

NODE'S NUMBER: 145                       NODE'S TYPE: 4
NODE'S DESCRIPTION:[illegible] FINISHED
----------------------------------------------------------------------
PRE-NODE'S NUMBER: [illegible]           SUCC-NODE'S NUMBER: 150
                          MIN            MAX          MEAN          S.D
                        -------        -------       ------       -------
WAITING TIME:        [illegible]     [illegible]      2.249        0.7532
**********************************************************************
```

Figure (82)- Continued.

```
NODE'S NUMBER: 155                        NODE'S TYPE: [illegible]
NODE'S DESCRIPTION:COST ACCUMULATION
--------------------------------------------------------------------------
NO.OF.NODES PRECEEDING ACC-NODE= 3        SUCC-NODE'S NUMBER: 2410
**************************************************************************

NODE'S NUMBER: 160                        NODE'S TYPE: 1
NODE'S DESCRIPTION:SITE-OVERH-COST
--------------------------------------------------------------------------
PRE-NODE'S NUMBER: 150                    SUCC-NODE'S NUMBER: 2410
COST/TIME UNIT= 1000
                          MIN          MAX          MEAN          S.D
                       --------     --------      -------       -------
COST PARAMETER:       213478.751   226797.172   220557.062    2419.375
**************************************************************************

NODE'S NUMBER: 170                        NODE'S TYPE: 4
NODE'S DESCRIPTION:S-READY(INT-D-EXCAV)
--------------------------------------------------------------------------
PRE-NODE'S NUMBER: 165                    SUCC-NODE'S NUMBER: 180
                          MIN          MAX          MEAN          S.D
                       -------      --------      -------       -------
WAITING TIME:            0.000        0.000        0.000         0.0000
**************************************************************************

NODE'S NUMBER: 175                        NODE'S TYPE: 3
NODE'S DESCRIPTION:S-READ (EXT-D-EXCAV)
--------------------------------------------------------------------------
PRE-NODE'S NUMBER: 165                    SUCC-NODE'S NUMBER: 2195
                          MIN          MAX          MEAN          S.D
                       -------      -------       ------        -------
WAITING TIME:            1.019        1.924        1.469         0.1936
**************************************************************************

NODE'S NUMBER: 185                        NODE'S TYPE: 4
NODE'S DESCRIPTION:INT-D READ (BEDDING)
--------------------------------------------------------------------------
PRE-NODE'S NUMBER: 180                    SUCC-NODE'S NUMBER: 190
                          MIN          MAX          MEAN          S.D
                       -------      -------       ------        -------
WAITING TIME:            0.000        0.916        0.116         0.2282
**************************************************************************

NODE'S NUMBER: 195                        NODE'S TYPE: 4
NODE'S DESCRIPTION:INT-D READ(PIPE LAY
--------------------------------------------------------------------------
PRE-NODE'S NUMBER: 190                    SUCC-NODE'S NUMBER: 200
                          MIN          MAX          MEAN          S.D
                       -------      --------      -------       -------
WAITING TIME:            0.000        0.000        0.000         0.0000
**************************************************************************

NODE'S NUMBER: 205                        NODE'S TYPE: 4
NODE'S DESCRIPTION:INT-D READ(BACKFILL)
--------------------------------------------------------------------------
PRE-NODE'S NUMBER: 200                    SUCC NODE'S NUMBER: 210
                          MIN          MAX          MEAN          S.D
                       -------      ---           -------       -------
WAITING TIME:            0.000        0.000        0.000         0.0000
**************************************************************************

NODE'S NUMBER: 215                        NODE'S TYPE: 4
NODE'S DESCRIPTION:INT-D-WORK FINISHED
--------------------------------------------------------------------------
PRE-NODE'S NUMBER: 210                    SUCC NODE'S NUMBER: 220
                          MIN          MAX          MEAN          S.D
                       ---          -------       ------        -------
WAITING TIME:            0.000        0.000        0.000         0.0000
**************************************************************************
```

Figure (82)- Continued.