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THE USE OF COMPUTERS IN CONSTRUCTION MANAGEMENT

BY

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THESIS

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ABSTRACT

A study on the use of computers for the management of construction projects has been conducted. The findings of this study will be presented here and will consist of:

1. An examination of the different utilization of computers in the field of construction management.

2. An analysis of the methodology of some well known computer software packages used by many construction companies.

3. A complete documentation of computer codes that have been developed
   a. to illustrate the use of computer graphics for an effective utilization of some construction management techniques such as the bar chart
   b. to solve the problem of resource leveling with a method named the Minimum Moment Algorithm.
ACKNOWLEDGEMENT

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CHAPTER I
INTRODUCTION

In these days where the use of computers has spread in almost all our daily activities, it is not amazing that the computer is an indispensable tool in the field of management. This thesis will be a study of the use of computers in the area of construction. The objective is to provide the reader with a complete knowledge of the use of computers at different levels of management of a construction project.

With its ability to handle large amounts of data very quickly, a computer might be the right answer to many types of management problems. However, the choice of a computer system for a particular construction firm must be made carefully. Different options will be analyzed along with the advantages and the problems that can arise when a construction firm decides to install an in-house computer system.

The next step of this study will be a review of the applications of a computer for:

1. planning and scheduling
2. cost control
3. design and graphics
Some commonly used computer packages will be examined. These ready-to-use computer programs which are available on the market have different applications. They range from payroll and cost estimating to bid analysis and advanced types of simulation.

Finally, three computer codes will be presented in order to familiarize the reader with the application of computers in two different areas: scheduling and resource allocation.

The first two programs will illustrate the use of computer graphics with a technique often used in construction management, the bar chart.

The last program gives a solution to the problem of resource leveling.

Among the packages presented up to now, none of them deal with the subject of resource allocation. Therefore, an approach well suited to the construction field is used to write a computer code that will do the leveling of a resource within a fixed project duration.
CHAPTER II

JUSTIFICATION OF THE USE OF COMPUTERS

Reasons for Acquiring a Computer

The use of computers by an engineering firm can be made through the service of a commercial bureau or with the installation of its own computer system. There are a lot of inconveniences when using a commercial organization. The related difficulties will be reviewed and the process for the acquirement of computers by a construction company and the advantages and disadvantages of in-house computer services will be studied.

Even though the use of computers was started in the 1950's, "the whole subject (computers) is surrounded with an air of mystery and confusion" (Campbell, 1975). This is due mainly to a problem of communication. The difficulties encountered become more evident when the computing facilities are provided by an outside commercial organization, out of the control of the interested engineering firm.

The services of these commercial bureaus can be supplied in three different ways: hire computing time, contract jobs, or use standard application programs. Because of the way this service is supplied, the lack of control over these programs is the major concern of the engineer who has to submit to the bureau the parameters of his problem according to the program instruction manual. This manual is usually the main obstacle to a profitable use of the
programs available to the engineer. The main complaints were that they did not have enough diagrams and examples, the tests were too long and too many computer terms were encountered. As a result of the difficulty to understand the user instruction manual, the preparation of the input data became arduous.

Other problems were turn-around times which affect production and cost and varies from bureau to bureau, data punching errors and the last, but not the least concern, was the cost of using the service bureau. This cost included: cost of computer central processing unit, input/output, connect time, data storage rental, telephone lines, terminals, and personnel travel. In addition, a company which does not have its own computer facilities will tend to always depend upon a service bureau and will not develop its own software.

It is in order to avoid all these inconveniences that more and more construction companies are acquiring computers for their own use. This is a decision that should be made very carefully. First, the firm must conduct a feasibility study in order to establish the adequate in-house computer system. Whether it is for the first time purchase or for the replacement of an existing computer, the justification of the system should be based upon proper financial analysis. These are the steps that should be followed. The engineer must (Tonias, 1981):

1. identify his present situation
2. determine to the best of his ability his objectives
3. define his computing needs

4. plan a program of computer solicitation in an organized and thorough manner.

Now the advantages and problems that could come from the implementation of a computing system will be evaluated.

Advantages

There are many benefits that result from the use of a computer. The following ones will be analyzed: speed, economy and accuracy.

Speed

This is the main characteristic of the computer. The slogan, "time is money", is well known; by using a computer, a company will save time and, therefore, save money.

The computer manipulates data and information many thousands of times faster than a person can. Since the most frequent problem that a construction manager has to deal with is the completion of a project within tight schedules, the use of a computer can be very helpful to him. It will give the manager the ability to decide quickly by providing him with information that would otherwise take more time to be known. It also plays a preventive role by giving early warnings on problems and, therefore, avoid some usually unpredictable events. In addition, updated schedules can be maintained during the whole duration of the project along with continuous updating of the amount of work performed or money spent. This will promote the use of more construction planning methods. In
the past, the methods were abandoned before the completion of a project because it took too much time to update the schedules and adjust them accordingly to the progress of the project and the changes that had occurred.

A computer, as we see, can reduce the time spent in managing a project and, therefore, the duration of the whole project.

Economy

This aspect is the main one that is considered during the feasibility study. When is it more economical to use a computer instead of manpower? There is a break-even point beyond which the cost saving grows rapidly as the volume of data processed increases.

The computer provides the company with manpower augmentation. Instead of having to do repetitive but easy calculations over and over again, personnel can be shifted to other more productive activities, because a computer will never get bored or tired of doing them. Another advantage is the flexibility of a computer system. Unlike manpower, the volume of work in a company varies with time. It increases when the company gets a contract and so does the need for personnel. If the firm used only manpower, it would have only two choices: (1) hire and fire personnel depending on the work load. The inconveniences of this solution are obvious: qualified personnel are difficult to acquire and once you get them, one does not want to lose them. Now, with the acquisition of computers, a company will just have to operate or not operate them instead of hiring
or firing people as the work load varies. (2) The other alternative is to keep the same amount of workers, then when the work load diminishes, the workers would be idle, and the firm would have to pay them just to keep them.

Another aspect of the flexibility of a computer system is its instantaneous reversibility: a company does not know in advance whether it is going to be awarded a contract or not; if it gets the project, the acquisition of additional persons can take weeks or months and when dealing with multimillion dollar projects, it is clear that this is a very risky situation that can even lead to bankruptcy.

For example, one company had a manpower ceiling imposed. A study revealed that four more schedulers and planners would be needed to collect and process the data needed for the project. The development and implementation of a CMS (computer-aided management system) with a record of proven success allowed the existing staff to satisfy project objectives. In addition, the cost of the smaller staff and CMS was $8,000 less than if the work was all done manually with a larger staff (Samaras, 1979).

Using an in-house computer can be more profitable than using manpower or a service bureau. The main reason is the tremendous decrease in the cost of computer hardware in the past years. Manpower resources is a major investment; if the use of a computer, as mentioned previously, augments the manpower capability through
effective use in more productive tasks, then it will consequently decrease the number of employees needed and, therefore, reduce the expenditure on personnel. Compared to a service bureau, the economic advantages of an in-house computer system are evident when "the average monthly expenditure for the service bureau exceeds 75% of the monthly rental or lease of appropriate in-house computer" (Tonias, 1981). The economic benefits of a computer system are, therefore, related to the internal organization and the needs of each company considered individually.

Accuracy

The computer is a very precise tool. Even during the processing of large volumes of data computer accuracy errors are almost nonexistent. In the construction industry, an error can be fatal, whether it is made during the estimating or the scheduling process. When bidding for a project, a construction company tries to submit the lowest bid and, at the same time, it attempts to make as much profit as possible. If, due to an estimating error, a manager underestimates the cost of a project and if the contract is awarded, the firm might not make any profit and this miscalculation could cause a certain amount of deficit proportional to the magnitude of the error. The estimating and the scheduling of a multimillion dollar project means dealing with thousands of activities and millions of items. It is very likely that the use of manpower, even the most qualified, will generate some errors. As a result of using a computer,
errors of computation will be avoided, fewer inspections and recalculations will be needed and, therefore, time and money will be saved.

**Problems**

There are some problems that are encountered when a computer system has been implemented. They must be considered carefully to avoid a failure of this new system.

**Confusion**

To enjoy the benefits of a computer, the manager and his staff must give some assistance, usually more than they would expect. The tendency is to think of the computer as a magic tool. They do not really know what to expect from it, what it can and cannot do. The user is tempted to expect more from the computer than it is possible to get. As a result, the user can often be disappointed. To reach the potential of the new system, the user must clearly understand its role. The documentation that comes with the computer or the programs are often not clear and are, therefore, difficult and time-consuming to use.

Another obstacle is the mystery that has surrounded the computer for a long time. Engineers were reluctant to use this unknown tool. Now, this problem is practically surmounted, since these days civil engineering students are familiar with computer science and, therefore, these graduates will be less resistant to use the computer in their work.
Discipline and Control

When using any kind of computer system, recruiting qualified personnel is a must. To function, the computer needs input. Most of this must be entered manually according to a specified format. This requires a lot of discipline and accuracy from the person in charge of the entering of data. If the work is not done properly, it will result in errors that could be avoided if the operator was more cautious. In many cases, the computer will detect errors and return the data for correction, but this will imply delay of the results.

Sometimes an error message from the computer might not send the user directly to where it occurred; it will take more time than expected to detect an input error.

The administration must be aware that some kind of discipline or surveillance must be maintained in the environment of the computer. In a big company, many departments will have access to the use of a computer system. Which one has the priority? There is also a problem of providing the amount of user support necessary for a large scale installation. Data processing training will have to be maintained in the long range, especially when new technology is introduced, so that the employees can effectively utilize computing services. These matters must be handled adequately. If not, they will result in a waste of time that can nullify the advantages gained from the rapidity of a computer.
Making the Right Choice

With the wide variety of computers available, it is difficult to choose the one that is appropriate to the needs of the company. First, the manager must have exactly in mind what he wants to use the computer for. This decision can be difficult to make when it is a person in charge of a firm that usually contracts large projects. In this case, the computer can be needed for different kinds of tasks: simple quantity take-off to the more advanced calculation of a network-based system. The decision involves the choice of computers and also programs suitable to the entire company. Developing new programs or modifying existing programs is very costly and consumes a considerable amount of time. In light of this, it is very important to select the appropriate programs; the range of software available is very wide and is increasing rapidly. Therefore, choosing becomes more and more difficult. If a poorly designed program is picked, it will be very difficult to use. Errors in the input become more frequent because of misinterpretations of the program. It will also be difficult to determine the various limitations of the program and this is another source of errors.

There are many aspects that must be considered when choosing the hardware. Besides the fact that management must keep in mind that computers and program selections cannot be treated separately, the following points should be examined carefully:

1. processing mode: batch processing or interactive processing

2. memory size: minimum of 64KB (kilobytes)
3. multiprogramming: partition of the memory by user programmer or operator

4. auxillary memory such as magnetic disks

5. card reader

6. printer and related features

7. terminals

8. pen plotter

9. computer language (Basic, Fortran or Pascal)

After analyzing all of these options one by one and making the appropriate choice for each one of the previous devices, a system will be implemented that should respond almost exactly to the needs of the company. If the system is not sufficient, the firm still has the possibility to extend it through the connection to a large-scale computer by a communication network. There again, the choice must be cautious because the cost increases with the distance to be covered by the lines making the connection.

The wide variety of alternatives available for the selection of a computer system increases the possibility for having the one that fits exactly. On the other hand, this variety slows the process of deciding on the adoption of a complete computer system.

Once a system is chosen, its possibilities should be exploited to the maximum. In the next chapter the different applications of computers in construction will be studied.
CHAPTER III
APPLICATIONS

Planning and Scheduling

The utilization of computers has not changed the planning and scheduling techniques we are accustomed to, such as the bar chart. The CPM/PERT (Critical Path Method/Program Evaluation and Review Technique) is still used. What has changed is the ability, provided by the computer, to process large numbers of tasks very quickly, with almost no errors. As a result of its rapidity, the computer can perform different kinds of analyses that would be almost impossible to carry out manually on large systems involving hundreds and sometimes thousands of activities. For example, one can ask the computer to sort the activities according to a specific pattern, such as by slack value or degree of criticality. The computer can also interpret the results. For example, by comparing the due dates and effective completion dates, it can identify overdue activities.

No one can imagine managing a construction project successfully without a good plan. It can help the manager to complete a project on time and with minimum costs.

As part of the planning process, a manager should determine whether or not he will use a computer system and if so, how he will do it.
Use of the Computer in Planning

If the decision is that management will make use of a computer system, it should take advantage of the services of this system from the first preliminary planning of a project.

Planning means to prepare a report plan. This will involve forecasting and, therefore, dealing with uncertainties. For that reason, planning should be flexible so that any changes can be handled easily without having to start the planning all over again.

In an average firm where the use of a computer is non-existent, the management does not take the time to update the plan each time a modification must be made because it is too time-consuming and too costly. The initial plan is just ignored. With a computer, the manager can easily predict all the possible outcomes resulting from one decision. The different resulting changes for different decisions can be easily combined and analyzed along with their impact on the project. The appropriate actions to be taken when a change occurs can be fed into the computer and their consequences can be evaluated in a short amount of time.

Planning should always come before scheduling, but this is not what happens in reality. Usually, these are functions performed at the same time. Most construction companies, especially the ones in charge of small projects, use the bar chart because it is easy to set up and easy to use. But this method takes only into account the scheduling aspect. The relationships between the activities is not considered. Therefore, by looking at a bar chart, one cannot tell which
activity is dependent on another one, and which should precede the other. As a result, it will not work for large projects because it does not allow the manager to predict the effect of the delay of one activity on other dependent activities.

For these reasons, CPM/PERT is a must in the planning of large projects. A network of the activities is built showing precedence and dependency relationships between them. When we are dealing with projects containing hundreds of activities, the building of a network can be very difficult, if not impossible, to do by hand. Therefore, the help of the computer is very welcome for the preparation of a big network schedule, whether it is an arrow diagram or a precedence diagram.

CPM, or critical path method, is often used with an arrow diagram. An arrow diagram is a network of activities in which the activities are represented by the links and the relationships between them expressed by the connecting nodes. Since CPM is activity oriented, it was natural to use it with an arrow diagram. CPM concentrates management attention on milestones or start and end events and ignores what is happening between these events. That is, it does not pay serious attention to the percent completion of each activity in managing a project (Samaras, 1980).

PERT, formerly Program Evaluation Research Task, and now Program Evaluation and Review Technique, is often associated with a precedence diagram. A precedence diagram is another type of network where the activities are represented by the nodes and the relationships by the
links. This network will be often used with PERT which is more event oriented than CPM, since in PERT the accent is put on the completion of the activities. Also in PERT, probability is introduced. The exact duration of an activity is unknown. With PERT, this duration is approximated by the expected time computed with the mean of three estimated times.

The PERT technique is mainly used in the manufacturing industry where the duration of an activity cannot be set by the experience of a contractor like it happens in the construction industry. Because CPM concentrates on the milestones, start and end events, it is mainly used in construction.

The calculation for the arrow diagram used in CPM are easily made on a computer because of the practical identification of an activity by two numbers indicating the starting node and the ending node.

A network of activities, whether it is an arrow or a precedence diagram, can be altered by different kinds of errors due to the manipulation of a large number of activities and their numerical designations. One type of error that can cause some major misinterpretations by a computer is the introduction of a loop in the diagram. The loop is a nonsense loop considering the logic of a network. Fortunately, some procedures are available to detect and locate such errors when the network is computerized.

In an article entitled, "Scheduling Network Loop Detection" (Crandall, 1977), an algorithm is examined which can be used to locate loops in a precedence network, but can also evaluate loops in arrow networks after the application of another algorithm.
Computers are not only used with network based systems during the planning stage. They have some other applications such as the use that is made of it to produce various kinds of reports. These reports will help management to decide and forecast deficits and expenditures; the use of the computer to generate these reports will reduce the planning labor and time costs.

Case in Point: At one company on the East Coast, manual integration of cost, time and manpower was done routinely for management. This process consumed six man-weeks of work for each integrated report produced. Because the cost and long elapsed time (one to two weeks to produce the report), an integrated CMS was implemented. After smoothing out the system bugs, an integrated report took one day to produce using one man-day of effort. The net savings to the company, accounting for the increased computer costs, was $3,600 per report produced (Samaras, 1979).

Also, the graphs and tables easily generated by the computer facilitate the interpretation of the data available and, consequently, the planning process.

Use of Computers in Scheduling

When the planning is completed, the scheduling of the activities can begin. It starts with time analysis which involves the breaking down of a task or project into various logical activities and assigning start and end dates to them based on their scope, complexity, and uncertainty (Samaras, 1979). The scheduling process can be stated simply as the fact of estimating activity durations and calculating earliest and latest event time and project overall duration. During the planning stage, the main goal is to divide the job into
elemental activities and specify the order in which they were to be executed. After the completion of the planning process, time is introduced in the diagrams where previously it was not taken into consideration. It is during the scheduling phase that the critical path is calculated. This will determine the project duration since, by definition, the critical path is the chain of activity in the network having the largest total time, when their duration is added. This time represents the minimum time for project completion.

Now the different contributions of the computer to the scheduling process will be analyzed.

**Speed and Accuracy**

Here again, these characteristics of the computer have been exploited. The calculations performed in a network for scheduling purposes are simple additions and deletions. The use of a computer allows the operator to save time when the network has a lot of activities, and to avoid mistakes since the computer is very accurate and reliable. Considering that an error at any point in the calculation is carried right through to the end of the network, one can appreciate the role of the computer in network computations. Another advantage is the availability of software packages. They are easy to use and save a great amount of time. Since all the calculation methods have all been built in the programs, the ready-to-use packages need only a small amount of information. The only data that must be entered are: a list of activities with the number of the event at which
it starts, the number of the event at which it finishes and the activity duration. The manager will just have to select which computation he needs to be performed and the output format desired.

Updating

Schedule updating is one of the most useful and important computer applications in the entire project management systems (Clough, 1979 and Sears, 1979). Once the network has been set up, it can be stored on magnetic tape or floppy disk. Therefore, if any change is required, only the new data need to be entered and a new calculation of the whole network is made very quickly. These calculations can be repeated as often as desired and the results can also be saved. This flexibility of the computer and the software allows the manager to make the necessary adjustment before the beginning of the project. It is occasionally needed to redefine certain activities, to condense others in fewer activities or expand them in additional ones. Sometimes after the calculation of a network, the resulting project-completion date does not meet with the required contract completion date. This is the type of problem that must be corrected quickly and accurately.

Once the project has started, the schedule must be continuously updated according to the progress of the work. Thanks to the use of the computer, this surveillance can be maintained easily. One can indicate in the schedule work activity has been completed, which one has been delayed and the effect on forthcoming activities. It is
very frequent that management has to replan and, consequently, re-schedule for the future. With the computer, this is an easy task.

Output Format

Another accommodation offered by the computer is its ability to sort and arrange the output in different ways.

1. The activities can be listed in any sequence desired. For example:
   a. in sequence of their early start date
   b. by activity number
   c. by total slack or float (indicating the degree of criticality)

2. Most of the computer programs provide the user with many options for the formatting of the calendar of the schedule. He can choose actual calendar dates or he can just indicate the order by a number. The user can also choose the unit time as weeks or months.

3. It is possible to introduce some description code and use it to relate activities of the same type. Therefore, it will be possible to print out separately work related to different domains. For example, plumbing can be separated from electric installation.

4. Another feature is the capability of some programs to print out the activities as a bar chart. The bar chart is simple, easy to understand and easy to update. The actual performance of each activity can be indicated on the same chart.

The bar chart will be studied more deeply in the next chapter.

This ends the study on the role of computers in planning and scheduling.

Use of Computer for Cost Control

Cost control is the most common utilization of computers in management. The basic cost accounting operations, such as payroll,
are handled easily by the computer. In construction management, some more advanced and specific cost control operations are performed. The use of the computer allows the manager to handle with ease the more complex calculations that are performed in this field.

In this section, we will first study how the computer is used in the accounting area, e.g., quantity record keeping, accounts payable. Then, we will take a look at some applications specific to the field of construction management such as estimating or cash flow analysis.

All these operations must be processed accurately because the most important base of cost-related project management is the reliability of the cost information. The degree of reliability depends on the precision of the cost estimates. Important decisions to be taken will depend directly on the aforementioned reliability (Trefzer, 1981).

Using a computer will guarantee the accuracy and precision needed for the results obtained from the estimating. The following statement will summarize the way computers are used by contractors:

Construction contractors responding to a 1982 Auburn University computer questionnaire indicated that they were generally well satisfied with commercially written software that performs the basic accounting and job cost related tasks. Most construction managers with annual work volumes of $10,000,000 or less were not, however, utilizing their small computers for tasks that required a great deal of in-house computer programming skill. This may, in fact, be a significant future trend in small computer utilization (Bell, 1983).
Project Evaluation

The cost control procedure starts a long time before the beginning of the project. It starts with the estimating and other analysis necessary before the company goes for the bidding of a project. One of the most important aspects that a construction company takes into account before considering bidding on a project is the "rentability" of the project.

In this perspective, it becomes more and more vital to the engineer or construction manager to evaluate project benefits and costs over time. This evaluation, here again, deals with the manipulation of large volumes of data in the case of a big project. Therefore, a computer based system becomes an imperative.

A very frequent study that is made is the determination of the benefit, cost and benefit/cost ratio over time so that the effect of inflation and interest rates can be predicted and evaluated.

A construction firm is usually interested in the cost of a project and the maximum profit realizable (this aspect will be considered more deeply in the risk analysis and bidding strategy section later in another chapter). For a public project, profit is not the main objective. The evaluation is more difficult because some of the benefits cannot be easily quantified. The benefit-cost analysis of a public project is done over a long period of time, sometimes over 50 years.

The project evaluation system (PROEVS) described in the Proceedings of the Conference on Computers in Civil Engineering, intends to
help engineers and planners in performing benefit cost analysis whether it is for a private construction industry or for public projects. Benefit-cost analysis refers to a formal analytical procedure incorporating the project objectives in identifying alternative solutions which may yield the required benefits at the lowest cost (Chalabi, 1981). What is the role of the computer? PROEVS is a computer based system and by analyzing its functions, one can appreciate the role of a computer in cost analysis for construction projects.

The program presented performs the tasks of the executive, data adjustment, presentation of historic data, plotting benefit cost ratios of proposed projects, updating of project data and maintaining the master file. For more details on this program, see the reference on Chalabi (1981).

Spreadsheet

This is one of the most common uses of computers in business management. The low cost of microcomputer hardware and the easy to use software packages have made this procedure available to all microcomputer users. Spreadsheet packages such as Visicalc, Supercalc, Easycalc, Freecalc, etc., provide the construction industry with a very versatile tool that has a wide range of application in construction management. What is a spreadsheet and what can it do? Electronic spreadsheet programs provide the microcomputer user with a large table or worksheet that contains hundreds of rows and a certain number of columns of coordinate locations (254 rows and 63 columns in the
case of the Visicalc package. Labels, values or formulas are input into the worksheet by moving a cursor (lighted bar) to the desired coordinate location. The formula entered into a defined coordinate is written in terms of the input data that have been entered into other positions. These data are designated in the formula by the coordinate of their location. The results of the requested computations appear in another column and can then be used in other formulas. Moving the cursor in the desired coordinate and changing a data located at this position will result in an immediate recalculation of the corresponding variable. The ability to selectively alter input variables after examining the previous program output is a very valuable feature, particularly when a large number of input variables are present (Bell, 1983).

Because of its versatility and the ease with which it can be manipulated, the electronic spreadsheet has a lot of capabilities.

Use of the Spreadsheet in the Construction Industry

A survey indicated that approximately 90% of the small computer users in the construction industry were utilizing comprehensive software packages for accounting functions related to general ledger, accounts payable/receivable, payroll and job costs (Bell, 1983). Around 30% of them used their computer for estimating and even fewer for tasks specific to the construction management field, such as bid analysis or inventory control.

The spreadsheet, hopefully, offers some specific construction related application. It can be used for equipment replacement
analysis and estimating. The equipment replacement analysis problem is a situation where the user takes advantage of the ability of the spreadsheet to create alternate solutions corresponding to different problem assumptions. In this case, the objective is to determine the effect of the alternate values of projected use rates, interest rates, inflation rates, maintenance costs, salvage value, etc.

When necessary calculations are executed, the decision to "trade now" or "trade later" is made.

Estimating is another potential of an electronic spreadsheet. The user can easily input, manipulate and store the parameters to estimate. The quantity takeoff is simplified and, as a result, the estimating process is accelerated. The formulas entered for one quantity takeoff can be repeatedly used to perform similar calculations for any project. For example, a sheet can determine volumes of foundation walls, and then can be used for any project that has foundation walls. After using the spreadsheet for quantity takeoff, the estimator has the possibility to enter unit prices for the pricing work. Cost and duration of activities can be calculated as soon as the quantity of work is known.

Other Techniques

The spreadsheet is not the only computerized method used for cost control. We are going to analyze two other typical computer based systems used mainly for cost-control in the construction industry. This will allow us to have a general view on the use of computers in this area.
The most famous one is DESSY–CONES (DESSY: DESign SYstem; CONES: CONstruction EStimate). It is a computerized construction quantity record keeping system. It consists of two parts: (1) DESSY assists the engineer in quantity take-off and computation, cost calculation, and preparation of final contract documents and (2) CONES provides the engineer with expedient accounting and positive cross-referencing of field-placed construction items (Tonias, 1979). The system is based on the general concept of bookkeeping and accounting. The quantities can be entered directly or they can be computed by the system from their basic components. The preparation of the input can be made manually, by the use of a digitizer or other automatic device such as photogrammetric used to compute volumetric quantities of earthwork for direct input into either the DESSY or the CONES system. Then, the necessary documents and files are prepared. As in the scheduling stage, the files are updated as the quantities are estimated for a design project and each time a payment estimate is being prepared for a construction project. It is possible to relate CONES to construction progress schedule by relating its items to activities of a CPM project control network program. Also, changes of quantities and related records can be made easily and quickly because the design office can communicate directly via computer with the field office which gives important information about the modifications that have occurred on site.

Standardization, organization, neatness, speed, versatility, auditability, accurate accounting, and release of technical manpower for
the pursuit of technical endeavors are the objectives of such a system (Tonias, 1979). For more details on DESSY-CONES, see the reference by Tonias (1979).

Another computer-based method of cost-control is performed by means of standard costing in relation with the amount of information available in the respective project phase. The job is divided into elements and sub-elements for estimating purposes. This is the standard costing by elements. Then, the project costs are classified according to their nature. Standard costing gives the manager the possibility to estimate the investment for a planned construction project by allowing him to make a precise cost estimate and to forecast the cost consequences. The detailed classification of the costs, obtained when using the standard costing method, is made possible with the use of a computerized data base. The computer can easily store the work and work items by identifying them with a certain code. The code established is based on the functional element to which the work or the work items belong. This method offers a lot of possibilities; among them is the ability to produce detailed estimates of cost for a specific activity.

The described system has been developed in cooperation with an experienced construction estimating firm (Trefzer, 1981). CYCLONE, cyclic operations network, is another analytical technique for the analysis of construction processes. CYCLONE has been implemented on a microcomputer to provide a cost-effective means by which construction decision makers can compare various construction methodologies.
and conduct sensitivity analysis of a selected methodology to determine the optimal or best resource use (Lluch, 1982).

CYCLONE is a simulation method which takes a construction operation and breaks it down into a series of repetitive activities. The accent is put on how an operation is accomplished. The use of this digital simulation technique solves the construction process models and gives information regarding operation, productivity, system delays and the state (idle or active) of various construction resources such as cranes, crews or trucks. Construction operations, such as paving and precasting of concrete slabs, have been simulated with the Micro Cyclone program on the Apple II-Plus and the TRS-80 Model II. The cyclone system generates information which allows the user to monitor an event as it takes place. However, the cost and speculative return on investment of using computerized method at this level has resulted in little or no analysis being conducted on projects which are not at the super project level (Lluch, 1982).

With today's fast developing technology, new techniques are available to the manager for cost-control and estimate, and they are continuously improving. Now there are some sophisticated tools that will allow him to attain more precision, accuracy and rapidity in his work. One example is the use of digital terrain data for project estimating. It is used for work related to topography.
Bidding and Risk Analysis

Before the bidding of a project, all costs must be available to the project manager. He will submit his bid following the guidelines of his bidding strategy.

The data available for the schedule and the costs have been estimated. They are not known with certainty. Therefore, there is a certain amount of risk involved in the bidding procedure. The risks cannot be eliminated but their harmful effects can be minimized through consolidation, specialization, control, prediction, diffusion or selection (Park, 1979).

Risk analysis has the purpose of diminishing the degree of uncertainty not only in accompanying the estimated costs and schedules, but also the bid with regard to the bid of the other participating companies. The latest matter is known as competitive bidding.

In the case of estimating, the uncertainty comes from some factors that are not under the control of the management, such as inflation, interest rate, weather, disaster delays. Some other factors are more internal to the company and can be controlled. These are estimating errors, inadequate plans and specifications, and faculty workmanship.

The effect of different risk factors can be evaluated by means of a model. The resulting simulation problems are best solved with electronic computers. Simulation is not the only way to reduce risks due to uncertainty. Another method, the Monte Carlo Technique, is one of the many available. It is used to study the effect of random
factors on a project schedule and deals with a lot of random numbers generated by computers. This technique can be applied in different situations. For example, consider a problem involving queueing theory where trucks are expected to arrive during a certain time interval, but where their exact arrival times are unknown. Using the Monte Carlo technique, an adequate solution to the problem can be found by assuming the truck arrival times to be distributed completely at random, estimating their times from the random number table (Park, 1979).

Knowing the risk associated with the estimated costs and schedules, the managers can adjust the cost of a contract to accommodate these risks. One company was able to profitably reschedule work on one project within a larger program by instituting computerized risk analysis. Therefore, when submitting a bid or proposal for a new project, top management can determine if the contract offers sufficient financial incentive to justify a high probability of failure. Once the decision has been made to analyze the risk, the company should implement its computer system accordingly.

The systems analyst is responsible for developing the basic risk analysis program and for leading and coordinating the collection of accurate data to feed to the computer for analysis (Samaras, 1979). The role of management is to evaluate the output and discuss the probability of meeting the schedule or cost estimates. At least two estimates should be provided for each activity. It should also be decided who must supply the data for risk analysis.
After analyzing the data, the computer will provide the manager with the graphs and tables that will facilitate the decision process. For example, the system can give a graph of a range of project durations versus their probability of being obtained. The options offered by a computer system are very diversified and facilitate the probability studies made during the risk analysis.

But, there are some problems to watch out for. One of them is that a computer program may produce project schedule and cost estimates that are very inaccurate if the numbers are not checked to verify that they are reasonably close to intuitive risk assessments. The output report should also be reviewed with the person who provided the input data.

Now that the management has the necessary information about the risks associated with the schedules and costs estimated, it will be more confident about its bidding strategy.

Competitive bidding is another domain of management where there is a lot of risk involved. The main area of uncertainty is related to the bids that will be submitted by the competitors.

The objective of bidding strategy is to bid high enough to make a profit, and low enough to get a job—both at the same time (Park, 1979). To find the optimum bid, a number of probability studies must be undertaken, because this optimum varies with the number of competitors and their bid. As the number of competitors increases, the expected profit decreases. The calculation of the expected profit in different conditions must be made to identify the jobs that
offer the most profit opportunities, and should be considered for bidding.

The use of a computer facilitates the probability studies because it can analyze easily all the possible combinations for different numbers of competitors and different amounts of profit considered by the company. The use of graphs and tables prepared manually are not necessary. The computer can generate them automatically from the basic data.

The prime benefit provided by risk analysis is that of saving money by allowing management to more effectively use resources for maximum payoff (Samaras, 1979).

Use of Computers for Design and Graphics

Computer-aided design and drafting (CADD) is a rapidly growing field because of the many advantages it can offer to any engineering environment. The design engineer can gain a lot from the main qualities of a CADD system. First, the computer is never tired of redrawing or modifying. Therefore, the engineer can modify a plan as often as he wants to until he finds the appropriate design. The computer is quick and accurate. Therefore, it will provide the builder with results and drawings that will allow him to decide quickly regarding the feasibility of a project. The plan can be plotted in hours, not days, and with a high degree of accuracy. Civil engineers must move to the efficient use of computers to design and draft or lose out. It is the only way to be competitive.
Civil engineers are now using obsolete technology. The average cost to produce a final drawing for a typical subdivision manually is about $12.50. Produced using the computer, that same drawing costs $2.50. Such are the sentiments of Hector Holguin (Seltz-Petrash, 1980).

In the construction management field, the use of computers to design and draw is also widespread, mainly for the drafting work. With a CADD system, a material quantity take-off can be made using the drawings generated by a graphic facility. This facility consists of a graphic tablet, a graphic display, and a hardcopy unit with an associated computer. The measurement of the materials is done according to the following pattern. All the necessary elements are directly taken from the plan, coded and the vertical elements automatically generated by the program (Trefzer, 1981). The measurement can be followed on the screen of the graphic display. At the end of the procedure, the computations can also be displayed on the screen, making it easy to control the measured quantities. By using this technique, the manpower for the measurement has been reduced by 75%. Once a drawing has been made, it can be modified many times and used for different purposes. All the changes and the original can be saved in the memory of the computer for future use. This contributes, as expected, to a substantial cost savings. Some systems are very advanced, like the one developed by a Cornell University professor, Donald Greenberg. His computer graphic system
can translate structural, engineering and environmental data into pictures. It can also show the preliminary design improved by holding the lines out of sight. It can create for a building any background chosen by the designer. It even has the ability to estimate energy consumption based on geographical location and occupancy.

More examples on the use of computer graphics in construction management will be presented in the next chapter.

The use of computers for design is the use most engineers are familiar with. During the design process, the problems encountered are usually related to mathematics. Most of the time the engineer has to deal with equations and the complexity increases with the complexity of the structure. Now, there are software packages that are available and that allow an engineer to design five to six beams per minute.

With this kind of automation, the engineer and designer will be able to better employ their judgements, analyze more design alternatives and achieve more closely an optimal design.

Project control and project management can also be implemented through a computer-aided design system. The related applications will also be presented in the next chapter.
CHAPTER IV
EXAMPLE OF APPLICATION OF COMPUTER GRAPHICS

Drawing of a Bar Chart

Introduction

The bar chart or Gantt Chart has been used by project managers since the early 1900's. Today, it is still the most used construction management control technique because it is simple and easy to understand. It clearly indicates the starting and ending dates for each activity. The progress of the activity can also be indicated on the same graph by another line of a different color or pattern (e.g., dashed lines). A computer generated bar chart is easy to update; the new graph is produced quickly.

Theory

The theory behind the bar chart is very simple. The bar chart is a time-scaled graph that shows the period of time during which an activity occurs. Next to the description of each activity is a solid line extending from the start date to the end date, usually an early start and early finish date.

In the following program, one simple formula has been used:

\[ EF = ES + D \]

or for an activity, "I":

35
early finish date: EF(I) 

= early start date: ES(I) + duration: D(I)

The following notation has been used in the program:

Early start date: S(I)

Duration: D(I)

Program Documentation

Program Name: Bar Chart

Program Function: Generate the drawing of a bar chart

Program Input: 1. Duration of the project (month)
2. Month at which the project starts
3. Number of activities
4. Starting date of each activity (i'th week)
5. Duration of each activity (week)
6. Typical activities for a construction project, in order of their start date, are listed in the data statements

Program Logic: 1. Accept input as described above
2. Draw the border of the chart
3. Scale the space available according to the duration of the project and the number of activities. Draw a column for each month.
4. Give a number to each month, starting with number 1. Print the name of the month in each column, starting with the beginning month, as indicated in the input.
5. Draw one bar in each line, from the start date to the end date of each activity.
6. Read the data for the description of the activities. Print each of them in one line along with their number.

Program Output: A bar chart

Refer to Appendix A for a listing of this program.
Case Example

A construction manager is in charge of the construction of a warehouse. He would like to draw a bar chart to monitor the progress of the project. The data for the description of the activities along with their duration and starting date are in the following table:

<table>
<thead>
<tr>
<th>Activity #</th>
<th>Activity Description</th>
<th>Start Date (Month)</th>
<th>Duration (Month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Order rebar</td>
<td>0</td>
<td>2.5</td>
</tr>
<tr>
<td>2</td>
<td>Order steel</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Order doors</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>Order equipment</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>Move in</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>6</td>
<td>Clear site</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>7</td>
<td>Excavate</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Place rebar</td>
<td>2.5</td>
<td>0.5</td>
</tr>
<tr>
<td>9</td>
<td>Cast footings</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>Erect walls</td>
<td>4</td>
<td>2.5</td>
</tr>
<tr>
<td>11</td>
<td>Pour floor</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>Place roof</td>
<td>6.5</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>Install door</td>
<td>6.5</td>
<td>0.5</td>
</tr>
<tr>
<td>14</td>
<td>Install equipment</td>
<td>7.5</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>Clean up</td>
<td>9</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The total duration of the project is 10-1/2 months. After loading the program, the computer will ask for the starting date of each activity and then for the duration of each activity. When all the information needed is entered by the user, the screen will be cleared and the drawing of the bar chart will begin.

Refer to Appendix B for an output of this program.
Fenced Bar Chart

Introduction

The Gantt Chart presented one major inconvenience: it did not show the relationships between the activities. That is why another type of bar chart has been created, the fenced bar chart. This chart shows the logic of a network of activities, without having the complexity of an arrow or precedence diagram. In the fenced bar chart, fences have been added. They indicate the dependency constraints between the activities. The activity on the left of a fence is like the trunk of a tree and must be completed before any of the activities (branches) on the right side of the fence may start (Melin, 1981).

The fenced bar chart is like a time-scaled arrow diagram, where the length of a link is proportional to the duration of the corresponding activity.

Theory

The theory behind this method is the same as the one used for the Gantt Chart. The dependency relationships between the activities has been added to the previous program.

Program Documentation

Program Name: Fenced Bar Chart
Program Function: Generate the drawing of a fenced bar chart
Program Input: 1. Duration of the project
                2. Month at which the project starts
3. Number of activities
4. Description of each activity
5. Starting date of each activity
6. Duration of each activity
7. For each activity, the following activity that depends on it

Program Logic:
1. Accept input as described above
2. Draw the border of the chart
3. Scale the space available according to the duration of the project and the number of activities
4. Give a number to each month, starting with number 1. Print the name of the month in each column, starting with the beginning month as indicated in the input.
5. Draw one bar in each line, from the start date to the end date of each activity
6. Draw a horizontal line from the end date of one activity to the start date of the next activity that depends on it.
7. Draw a vertical line (fence) on the start date of one activity from the line corresponding to this activity to the line corresponding to the activity on which its start date depends
8. Read the data for the description of the activities. Print each of them in one line, preceded by their number of the activity that must succeed.

Program Output: A fenced bar chart

Refer to Appendix C for a listing of this program.
Case Example

The same case example will be studied. Here, units for the input of the start dates and durations will be "weeks" instead of "months". See the following table.

<table>
<thead>
<tr>
<th>Activity Number</th>
<th>Depends on</th>
<th>Activity Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1, 7</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2, 9</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>4, 13</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>

After entering all the needed information, the user will see the drawing of a fenced bar chart on the screen.

Refer to Appendix C for an output of this program.
Resource Leveling

Introduction

The problem of resource allocation has been studied under different approaches; but, none of the methods proposed led to a satisfactory solution which was easily applicable to a construction project. Because in construction the contractor needs to level the resources without extending the project duration, his problem is referred to as "unlimited resource leveling" where there is no constraint with regard to the level of a resource. This is different from the case of "limited resource allocation" where the goal is to minimize the project duration to meet fixed resource limits.

A method is presented here that will minimize the level and, therefore, the costs of the resource while keeping the project duration fixed. The method is named "Minimum Moment Algorithm". Although the term "algorithm" is not exact, the method gives a direct solution without taking any random decision at any point during the procedure.

Theory

The minimum moment method is used with an arrow or precedence diagram (here an arrow diagram is used) and it is assumed that an activity cannot be split.

The algorithm assumes an early start scheduled desired derived from the CPM network computations, shifts the activities to the
right (using their free float) and shifts those that are not necessary to maintain the resource constraints back to the left (using their back float) (Harris, 1978).

A new quantity, the sum of squares of the daily resource sums, has been introduced as a means to determine the quality of the leveling. Another quantity, the "improvement factor", is used to select which activity should be shifted. The activities are examined accordingly to their sequence step.

The sequence step of an activity is defined as "the earliest logical position in the network that an activity can occupy while maintaining its proper dependencies" (Harris, 1978). In this program, the sequence step is computed using a forward pass calculation as if the early start and early finish were computed. The sequence step number of the activity is the resulting start step number.

The minimum moment method is based on the following theorem:

When a given set of elements is arranged into a histogram over a fixed set of intervals, the minimum moment of the elements exists when the histogram is a rectangle over the fixed set of intervals (Harris, 1978).

The leveling process tries to have the histogram of the resources as close as possible to this minimum.

The improvement factor is used to measure the reduction of the moment histogram for each shift, using the sum of squares of the daily resource sums, which determine the moment of the histogram. Before shifting an activity, the moment is:
where \( x_1, x_2, \ldots, x_m \) is the set of daily resource sums. Therefore:

\[
\{X\} = \sum_{1}^{m} x_i
\]  

(2)

from which \( m \) daily resource rates, \( r \), are to be deducted. Also, \( w_1, w_2, \ldots, w_m \) is the set of daily resource sums, where:

\[
\{W\} = \sum_{1}^{m} w_i
\]  

(3)

to which \( m \) daily resource rates, \( r \), are to be added (Harris, 1978).

After shifting the same activity, the moment is:

\[
M_2 = \sum_{1}^{m} (r_i - r)^2 + \sum_{1}^{m} (w_i - r)^2
\]  

(4)

After shifting, if the moment of the histogram diminishes, then \( M_2 < M_1 \). From this relationship, the improvement factor is deducted and is equal to:

\[
\text{IF}(\text{ACT},S) = r \left( \sum_{1}^{m} s_i - \sum_{1}^{m} w_i - mr \right)
\]  

(5)

This is the improvement factor for activity, \( \text{ACT} \), and shift, \( S \).

\[
m = \min (S, T)
\]  

(6)

where:
T = duration of the activity

S = day that the activity is to be shifted (S varies from 1 up to the free float of the activity)

In order to have an improvement in the moment histogram, the improvement factor must be positive.

Program Documentation

Program Name: Leveling

Program Function: Generate the optimum resource level histogram along with the corresponding new start day of the activities shifted.

Program Input: 1. Start node, II(I) and end node, JJ(I) for each activity I
2. Duration of each activity DUR(I)
3. Resource rate of each activity R(I)

Program Logic: 1. Accept input as described above
2. Calculate the critical path and the duration, TT, of the project along with the early start, ES(I), late start, LS(I), total float, TF(I), free float, FF(I) for each activity (Whitehouse, 1980)
3. Compute the sequence step, SEQUA(I) for each activity, and the number of sequence steps, NQ, in the diagram
4. Compute the resource level, LEV(D), for each day, D, of the duration of the project
5. Compute the number of activities, NAQ(Q) on each sequence step, Q
6. Starting with the last sequence step, NQ
   a. every activity, Y, on sequence step A(Q,Y) is examined
      (1) if the free float of the activity is zero: FF(A(Q,Y))=0, go to the next activity
      (2) if the resource rate of the activity is zero, shift the activity to the limit of its free float
      IF F(A(Q,V))=0, then ES(A(Q,Y)) = ES(A(Q,Y) + FF(A(Q,Y))
Determine new free float for the activities
(3) compute the improvement factor IF\(\phi(S)\) for each shift, \(S\) (\(S\) varies from 1 to \(FF(A(Q,Y))\)) using equation (5)

\[
IF\phi(S) = R(A(Q,Y)) \times (SUMX - SUMW - M \times R(A(Q,Y)))
\]

where: \(SUMX = \sum_{1}^{m} x_i\) (equation 2)

\(SUMW = \sum_{1}^{m} w_i\) (equation 3)

the maximum of \(IF\phi(S)\) for all the shifts is the improvement factor, \(IPF(Q,Y)\) of the activity considered

b. Choose the activity \(A(Q,KM)\) with the largest improvement factor: \(IPMAX\).

(1) if the largest improvement factor is negative (\(IPMAX < 0\)) go to the next sequence step

(2) if there is a tie in the value of the largest improvement factor (\(IPMAX\)) for several activities:

(a) select the activity with the maximum resource rate \((R(A(Q,Y)))\)

(b) if still tie, select the activity with the maximum free float, \(FF(A,Q,Y)\)

(c) if still tie, select the activity with the latest start date (maximum of \(ES(A(Q,Y))\))

(d) if still tie, select the activity which is the first in the queue (minimum of \(Y\))

c. Shift the activity subject to the following

(1) add the resource rate, \(R(A(Q,KM))\), of the activity shifted to each resource level of the days being occupied by the activity and subtract its resource rate from each resource level of the days being vacated by the activity. The shift made is noted \(M\phi(Q,Y)\) and corresponds to the shift \(S\) that gives the maximum improvement factor for an activity.
(2) If IPF(Q,KM) ties for different shifts, S, of an activity, the shift is equal to the maximum S:
\[ M\phi(Q,Y) = \text{MAXS} \]

d. If shifting has occurred in step c, update the early start date of the activity shifted:
\[ ES(A(Q,KM)) = ES(A(Q,KM)) + M\phi(A(Q,KM)) \]
and determine the new floats of the activities in the network.
e. Re-examine the activities on the sequence step b, until there is no shifting on this sequence step: \( M\phi(A(Q,KM)) = 0 \) (step a to step d)
f. Examine the next earlier sequence step (Q=Q-1) and repeat the same procedure for each sequence step (from steps a to e)
g. Repeat the algorithm from step a to step f until no more shifting takes place
\[ FF(A(Q,KM)) = 0 \]
for all the sequence steps (this is the end of the forward cycle where Q, the sequence step, varies from \( N_e \) (the last sequence step) to 1 (the first sequence step) and \( A(Q,Y) \) is an activity, Y, on sequence step Q, where Y varies from 1 to \( NAQ(Q) \), the number of activities on sequence step b.
h. Starting with the first sequence step and using the back float (BF) instead of the free float (FF), repeat the algorithm from steps a to g. (This is the end of the backward cycle and of the leveling).

The theory for the procedure is taken from the book by Harris (1980) which is a combination of the work of different authors.

Program Output:

1. Displays the sequence step of each activity and the number, NQ, of sequence step on this arrow diagram
2. Displays table with all activities with:
start and end node: II(I) to JJ(I)
eary start date: \( ES(I) \)
late start date: \( LS(I) \)
total float: \( TF(I) \)
free float: \( FF(I) \)
resource rate: \( R(I) \)
duration of the project: \( TT \)
3. Displays the value of the resource level for each day and then puts the screen on medium resolution graphic mode and displays the histogram of the resource levels for the project duration.

4. Displays (a) the improvement factor of each activity, Y, on sequence step Q for all the possible shifts, S, and (b) the improvement factor of activity, Y.

5. Displays the activity, KM, with the largest improvement factor on sequence step, Q, and the value of this improvement factor, IPMAX.

6. Displays the number of days activity, KM, on sequence step Q will be shifted; M*(A(Q,KM))

7. Put the screen on graphic mode and displays a new histogram after each shifting.

8. Displays a new table with the new start dates and floats after each shifting.

9. Displays the final values of the resource level for each day of the duration of the project.

NB: This program has been written for an IBM Personal Computer color display.

Refer to Appendix E for a listing of this program.
Case Example

Data for a construction project are taken from an arrow network and are given below along with the activity resource rates for a given resource (for example, man):

<table>
<thead>
<tr>
<th>i</th>
<th>j</th>
<th>Duration</th>
<th>Resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

A construction manager wants to find the best time to start each activity in order to have a good distribution of the resources during the progression of the project.

Before loading the program, the user must load GRAPHICS and then BASICA from the DOS disk. By typing "LOAD LEVELING", the resource leveling program is selected. The program is now loaded. The user starts the execution by typing RUN or pressing function KEY F2. The user will be asked to input the above data for each activity. Notice that the activities and their corresponding
data can be entered in any order. The program takes care of the final sequencing. The entering of the data is done as is shown in Appendix F. Appendix F contains an output of this program.
CHAPTER V
CONCLUSIONS

With the continuous evolution of computer science, the use of computers in any field of management will increase with time. In the construction area, the ready-to-use packages will increase in number and will become more and more sophisticated. Following the work done in this thesis, it is suggested for the future to analyze and criticize the most recent packages so that the future user can choose the one that fits his needs best.

On the other hand, one must keep in mind that the computer is not a magic tool. In order to give a solution to a problem, the computer must be fed with the guidelines that will lead to the solution. Also, each construction project is a special case, with its own difficulties. For these reasons, a construction manager should know how the solution to a general case is found so that he can modify the procedure and adapt it to his case, if needed. In this prospect, it is suggested that the program for resource leveling be extended for the following situations:

1. Need to level two or more resources at the same time
2. Case where the activities are assumed to be "splitable" (activities that can be started, interrupted and continued another time without affecting the logic of the network.

This concludes the study on the use of computers in construction management.
APPENDICES
APPENDIX A

PROGRAM LISTING: BAR CHART
*** NOTICE ***

IF THE OPERATION LISTED DOES NOT EXIST, ENTER 0 FOR THE STARTING DATE AND THE DURATION

ENTER N0: THE DURATION OF THE PROJECT (MONTH) ; " : N0=";

ENTER THE STARTING MONTH OF THE PROJECT (JAN=1, FEB=2 ...) ;

INPUT I0

ENTER N1: THE NUMBER OF ACTIVITIES ; " : N1=";

INPUT N1

M=130/N0

DIM SCN1>, DCN1>

PRINT *** DATA FOR STARTING DATE : I'th WEEK ***

FOR I=1 TO N1

PRINT "ENTER THE STARTING DATE OF ACTIVITY # " ; I ; " : S(" ; I ; ")=";

INPUT S(I)

S(I)=M*S(I)/4

NEXT I

PRINT *** DATA FOR THE DURATION OF EACH ACTIVITY : WEEK(S) ***

FOR I=1 TO N1

PRINT "ENTER THE DURATION OF ACTIVITY # " ; I ; " : D(" ; I ; ")=";

INPUT D(I)

D(I)=M*D(I)/4

NEXT I

PAGE AXIS M/4, 0, 0, 100

REM * DRAW CONTOUR *

DIM C0(4), C1(4)

DATA 130, 0, -130, 0, 100, 0, -100

READ C0, C1

MOVE 0, 0

DRAW C0, C1

REM * DRAW COLUMN FOR EACH MONTH *

FOR I=0 TO 130 STEP M

MOVE I, 0

DRAW I, 100

NEXT I

REM * PRINT THE # OF THE MONTH *

FOR I=1 TO N0

MOVE (I-1) * M, 95

PRINT I

NEXT I

FOR I=1 TO N0

S*="JANMARAPRMayJUNJULAugSEP" : S*="DECJANFEBMARAPRMayJUNJULAugSEP"

MOVE (I-1) * M+6, 95

B*="SEG(S*, (I0+I-2) * 3+1, 3)

PRINT B*

NEXT I

MOVE 0, 94.5

DRAW 130, 94.5

REM ** DRAW BARS **

FOR I=1 TO N1
660 \( \text{IO}=95-M0*1 \)
670 \( \text{II}=S(I) \)
680 MOVE \( \text{II}, \text{IO} \)
690 DRAW \( \text{II}+D(I), \text{IO} \)
700 MOVE \( \text{II}, \text{IO}+1 \)
710 DRAW \( \text{II}+D(I), \text{IO}+1 \)
720 MOVE \( \text{II}, \text{IO}+0.5 \)
730 DRAW \( \text{II}+D(I), \text{IO}+0.5 \)
740 MOVE \( \text{II}, \text{IO} \)
750 DRAW \( \text{II}, \text{IO}+1 \)
760 MOVE \( \text{II}+D(I), \text{IO} \)
770 DRAW \( \text{II}+D(I), \text{IO}+1 \)
780 NEXT I
790 REM * PRINT THE NUMBER OF EACH ACTIVITY & THE ACTIVITY *
800 M0=95/N1
810 FOR I=1 TO N1
820 IO=95-M0*I
830 READ A$ 
840 MOVE S(I), IO+1.25
850 PRINT I: " ;A$
860 NEXT I
870 REM * DATA FOR DESCRIPTION OF EACH ACTIVITY *
880 DIM A$(N1)
890 DATA "ORDER REBAR", "ORDER STEEL", "ORDER DOORS", "ORDER EQUIP."
900 DATA "MOVE IN", "CLEAR SITE", "EXCAVATE", "PLACE REBAR", "CAST PTGS."
910 DATA "ERECT WALLS", "POUR FLOOR", "PLACE ROOF", "INSTALL DOORS"
920 DATA "INSTALL EQUIP.", "CLEAN UP"
930 END
APPENDIX B

PROGRAM OUTPUT: BAR CHART
### NOTICE ###

**IF THE OPERATION LISTED DOES NOT EXIST, ENTER 0 FOR THE STARTING DATE AND THE DURATION**

**ENTER NO. THE DURATION OF THE PROJECT (MONTH)**: NO = 5

**ENTER THE STARTING MONTH OF THE PROJECT (JAN=1, FEB=2 ...)**: 1

**ENTER N1: THE NUMBER OF ACTIVITIES**: N1 = 15

#### DATA FOR STARTING DATE: 1'th WEEK ####

<table>
<thead>
<tr>
<th>Activity #</th>
<th>Starting Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S(1) = 0</td>
</tr>
<tr>
<td>2</td>
<td>S(2) = 0</td>
</tr>
<tr>
<td>3</td>
<td>S(3) = 0</td>
</tr>
<tr>
<td>4</td>
<td>S(4) = 0</td>
</tr>
<tr>
<td>5</td>
<td>S(5) = 0</td>
</tr>
<tr>
<td>6</td>
<td>S(6) = 1</td>
</tr>
<tr>
<td>7</td>
<td>S(7) = 2</td>
</tr>
<tr>
<td>8</td>
<td>S(8) = 5</td>
</tr>
<tr>
<td>9</td>
<td>S(9) = 6</td>
</tr>
<tr>
<td>10</td>
<td>S(10) = 8</td>
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<tr>
<td>11</td>
<td>S(11) = 8</td>
</tr>
<tr>
<td>12</td>
<td>S(12) = 13</td>
</tr>
<tr>
<td>13</td>
<td>S(13) = 13</td>
</tr>
<tr>
<td>14</td>
<td>S(14) = 15</td>
</tr>
<tr>
<td>15</td>
<td>S(15) = 17</td>
</tr>
</tbody>
</table>

#### DATA FOR THE DURATION OF EACH ACTIVITY: WEEK(S) ####

<table>
<thead>
<tr>
<th>Activity #</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>D(1) = 5</td>
</tr>
<tr>
<td>2</td>
<td>D(2) = 4</td>
</tr>
<tr>
<td>3</td>
<td>D(3) = 11</td>
</tr>
<tr>
<td>4</td>
<td>D(4) = 14</td>
</tr>
<tr>
<td>5</td>
<td>D(5) = 1</td>
</tr>
<tr>
<td>6</td>
<td>D(6) = 1</td>
</tr>
<tr>
<td>7</td>
<td>D(7) = 2</td>
</tr>
<tr>
<td>8</td>
<td>D(8) = 1</td>
</tr>
<tr>
<td>9</td>
<td>D(9) = 2</td>
</tr>
<tr>
<td>10</td>
<td>D(10) = 5</td>
</tr>
</tbody>
</table>
APPENDIX C

PROGRAM LISTING: FENCED BAR CHART
100 INIT
110 PAGE
120 PRINT " *** NOTICE *** "
130 PRINT " IF THE OPERATION LISTED DOES NOT EXIST, ENTER 0 "
140 PRINT " FOR THE STARTING DATE AND THE DURATION "
150 PRINT " "
160 PRINT " ENTER N0: THE DURATION OF THE PROJECT (MONTH):" ; N0=";
170 INPUT N0
180 PRINT " ENTER THE STARTING MONTH OF THE PROJECT (JAN=1, FEB=2 ...): "
190 INPUT I0
200 PRINT " ENTER N1: THE NUMBER OF ACTIVITIES:" ; N1=";
210 INPUT N1
220 M=130/N0
230 M0=95/N1
240 DIM S(N1), D(N1), Q(N1)
250 PRINT " *** DATA FOR STARTING DATE: I'th WEEK ***"
260 FOR I=1 TO N1
270 S(I)=M*S(I)/4
280 D(I)=M*D(I)/4
290 NEXT I
300 PRINT " *** DATA FOR THE DURATION OF EACH ACTIVITY: WEEK(S) ***"
310 FOR I=1 TO N1
320 PRINT " ENTER THE DURATION OF ACTIVITY # " ; I; : D(" ; I; ")=" ;
330 INPUT D(I)
340 D(I)=M*D(I)/4
350 NEXT I
360 PRINT " THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # " ; I; ; IS: # ;
370 INPUT Q(I)
380 NEXT I
390 PRINT " "
400 PRINT " "
410 PRINT " "
420 PRINT " "
430 PRINT " "
440 PRINT " "
450 PRINT " "
460 PRINT " "
470 NEXT I
480 PAGE
490 AXIS M/4, 0, 0, 100
500 REM " ******************* "
510 REM " DRAWING OF THE BORDER * "
520 REM " ******************* "
530 DIM C0, C1(4), C1(4)
540 DATA 130, 0, -130, 0, 0, 100, 0, -100
550 READ C0, C1
560 MOVE 0, 0
570 RDRAW C0, C1
580 REM " PRINT THE # OF THE MONTH *"
590 FOR I=1 TO N0
600 MOVE (I-1)*M, 95
610 PRINT I
620 NEXT I
630 FOR I=1 TO N0
640 S"="JANFEBMARAPRMAYJUNJULAugSEPDECJANFEBMARAPRMAYJUNJULAugSEP"
```
660 P$=SEG(S$, (I0+I-2)*3+1,3)
670 PRINT P$
680 NEXT I
690 MOVE 0,94.5
700 DRAW 130,94.5
710 REM ** DRAW BARS **
720 FOR I=1 TO N1
730 I0=95-M0*I
740 I1=S(I)
750 MOVE I1,I0
760 DRAW I1+D(I),I0
770 MOVE I1,I0+1
780 DRAW I1+D(I),I0+1
790 MOVE I1,I0+0.5
800 DRAW I1+D(I),I0+0.5
810 MOVE I1,I0
820 DRAW I1,I0+1
830 MOVE I1+D(I),I0
840 DRAW I1+D(I),I0+1
850 NEXT I
860 REM
870 REM ********************************************
880 REM * THE FOLLOWING WILL DO THE FENCING OF THE BAR CHART *
890 REM * THE ACTIVITIES DEPENDENCIES WILL BE INDICATED *
900 REM ********************************************
910 REM
920 FOR I=1 TO N1
930 MOVE SQCI)) 95-M0*I+0.5
940 DRAW SQCI>>) 95-M0*QCI>+0.5
950 MOVE SCI>+D<I> 95-M0*I+0.5
960 DRAW SCI + <I>>,95-M0*I+0.5
970 GIN X
980 PRINT "]";Q(I);
990 MOVE X,Y
1000 NEXT I
1010 REM
1020 REM ********************************************
1030 REM * PRINTING THE NUMBER OF EACH ACTIVITY & THE ACTIVITY *
1040 REM ********************************************
1050 REM
1060 REM
1070 FOR I=1 TO N1
1080 I0=95-M0*I
1090 READ A$
1100 MOVE S(I),I0+1.25
1110 PRINT I;" :A$
1120 NEXT I
1130 REM ********************************************
1140 REM ** DATA FOR THE DESCRIPTION OF EACH ACTIVITY **
1150 REM ********************************************
1160 DIM A$(N1)
1170 DATA "ORD.&DEL.REB.","ORD.&DEL.STEEL","ORD.&DEL.WIND."
1180 DATA "ORD.&DEL.EQUIP.","MOVE IN","CLEAR SITE","EXCAVATE","PLACE REB"
1185 DATA "CAST FTGS.","ERECT WALLS","POUR FLOOR","PLACE ROOF"
1190 DATA "INSTALL WIND.","INSTALL EQUIP.","CLN.UP"
1210 END
```
APPENDIX D

PROGRAM OUTPUT: FENCED BAR CHART
IF THE OPERATION LISTED DOES NOT EXIST, ENTER 0
FOR THE STARTING DATE AND THE DURATION

ENTER N0: THE DURATION OF THE PROJECT (MONTH): N0=5
ENTER THE STARTING MONTH OF THE PROJECT (JAN=1, FEB=2 ...) 1
ENTER N1: THE NUMBER OF ACTIVITIES: N1=15

*** DATA FOR STARTING DATE: 1st WEEK ***
ENTER THE STARTING DATE OF ACTIVITY #1: S(1)=0
ENTER THE STARTING DATE OF ACTIVITY #2: S(2)=0
ENTER THE STARTING DATE OF ACTIVITY #3: S(3)=0
ENTER THE STARTING DATE OF ACTIVITY #4: S(4)=0
ENTER THE STARTING DATE OF ACTIVITY #5: S(5)=0
ENTER THE STARTING DATE OF ACTIVITY #6: S(6)=1
ENTER THE STARTING DATE OF ACTIVITY #7: S(7)=2
ENTER THE STARTING DATE OF ACTIVITY #8: S(8)=5
ENTER THE STARTING DATE OF ACTIVITY #9: S(9)=6
ENTER THE STARTING DATE OF ACTIVITY #10: S(10)=8
ENTER THE STARTING DATE OF ACTIVITY #11: S(11)=8
ENTER THE STARTING DATE OF ACTIVITY #12: S(12)=13
ENTER THE STARTING DATE OF ACTIVITY #13: S(13)=13
ENTER THE STARTING DATE OF ACTIVITY #14: S(14)=15
ENTER THE STARTING DATE OF ACTIVITY #15: S(15)=17

*** DATA FOR THE DURATION OF EACH ACTIVITY: WEEK(S) ***
ENTER THE DURATION OF ACTIVITY #1: D(1)=5
ENTER THE DURATION OF ACTIVITY #2: D(2)=4
ENTER THE DURATION OF ACTIVITY #3: D(3)=11
ENTER THE DURATION OF ACTIVITY #4: D(4)=14
ENTER THE DURATION OF ACTIVITY #5: D(5)=1
ENTER THE DURATION OF ACTIVITY #6: D(6)=1
ENTER THE DURATION OF ACTIVITY #7: D(7)=2
ENTER THE DURATION OF ACTIVITY #8: D(8)=1
ENTER THE DURATION OF ACTIVITY #9: D(9)=2
ENTER THE DURATION OF ACTIVITY #10: D(10)=5
ENTER THE DURATION OF ACTIVITY # 11 : D(11)=4
ENTER THE DURATION OF ACTIVITY # 12 : D(12)=2
ENTER THE DURATION OF ACTIVITY # 13 : D(13)=1
ENTER THE DURATION OF ACTIVITY # 14 : D(14)=2
ENTER THE DURATION OF ACTIVITY # 15 : D(15)=1

ENTER THE # OF THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 1
& N.B. * IF NO ACTIVITY DEPEND ON ACTIVITY # 1, ENTER 1
THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 1 IS: # 8

ENTER THE # OF THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 2
& N.B. * IF NO ACTIVITY DEPEND ON ACTIVITY # 2, ENTER 2
THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 2 IS: # 18

ENTER THE # OF THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 3
& N.B. * IF NO ACTIVITY DEPEND ON ACTIVITY # 3, ENTER 3
THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 3 IS: # 13

ENTER THE # OF THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 4
& N.B. * IF NO ACTIVITY DEPEND ON ACTIVITY # 4, ENTER 4
THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 4 IS: # 14
ENTER THE # OF THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 5
* N.B.: IF NO ACTIVITY DEPEND ON ACTIVITY # 5 , ENTER 5

THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 5 IS: # 6

ENTER THE # OF THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 6
* N.B.: IF NO ACTIVITY DEPEND ON ACTIVITY # 6 , ENTER 6

THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 6 IS: # 7

ENTER THE # OF THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 7
* N.B.: IF NO ACTIVITY DEPEND ON ACTIVITY # 7 , ENTER 7

THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 7 IS: # 8

ENTER THE # OF THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 8
* N.B.: IF NO ACTIVITY DEPEND ON ACTIVITY # 8 , ENTER 8

THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 8 IS: # 9

ENTER THE # OF THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 9
* N.B.: IF NO ACTIVITY DEPEND ON ACTIVITY # 9 , ENTER 9

THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 9 IS: # 10
ENTER THE # OF THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 10
* N.B.* IF NO ACTIVITY DEPEND ON ACTIVITY # 10 , ENTER 10

THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 10 IS: # 12

ENTER THE # OF THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 11
* N.B.* IF NO ACTIVITY DEPEND ON ACTIVITY # 11 , ENTER 11

THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 11 IS: # 14

ENTER THE # OF THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 12
* N.B.* IF NO ACTIVITY DEPEND ON ACTIVITY # 12 , ENTER 12

THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 12 IS: # 14

ENTER THE # OF THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 13
* N.B.* IF NO ACTIVITY DEPEND ON ACTIVITY # 13 , ENTER 13

THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 13 IS: # 14

ENTER THE # OF THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 14
* N.B.* IF NO ACTIVITY DEPEND ON ACTIVITY # 14 , ENTER 14

THE NEXT ACTIVITY THAT DEPENDS ON ACTIVITY # 14 IS: # 15
APPENDIX E

PROGRAM LISTING: RESOURCE LEVELING
RESOURCES LEVELING

DEFINITION OF THE VARIABLES

I: START NO
II: END NO
DUR: DURATION OF AN ACTIVITY
ES: EARLY START
TF: TOTAL FLOAT
LS: LATE START
FF: FREE FLOAT
BF: BACK FLOAT
SEQ: SEQUENCE STEP
LEV: RESOURCE LEVEL FOR A DAY OR A TIME UNIT
NA: NUMBER OF ACTIVITIES
TT: DURATION OF THE PROJECT

CLS: KEY OFF
PRINT: "ENTER INFORMATION FROM YOUR ARROW DIAGRAM"
PRINT: "NUMBER OF ACTIVITIES (INCLUDING DUMMIES)";
OPTION BASE 1
DIM II(NA), JJ(NA), ES(NA), LS(NA), TF(NA), FF(NA), DUR(NA), SEQU(NA), RC(NA), STC(NA), BFC(NA)
PRINT "... DEFINITION OF THE NODES ...
FOR I = 1 TO NA
PRINT "ENTER ACTIVITY ...
FROM NODE ...
TO NODE ..."
INPUT I, II(I):
INPUT II(I):
IF II(I) < JJ(I) THEN 40
IF DUR(I) = 0 THEN 100
ST(I) = 0 ELSE ST(I) = 1
NEXT I
PRINT: "PRESS enter KEY TO CONTINUE";A$:CLS
FOR L = 1 TO NA-1
J = L
FOR K = L+1 TO NA
IF II(K) > II(J) THEN 440
IF JJ(K) > JJ(J) THEN 440
J = K
NEXT K
INTERCHANGING L & J

DETERMINATION OF THE SEQUENCE STEP OF EACH ACTIVITY

DUR(J) = 0 THEN ST(J) = 0 ELSE ST(J) = 1
NEXT J
FOR J = 1 TO NA
IF DUR(J) = 0 THEN 590 ELSE 600
ST(J) = ST(J) + 510
ST(J) = ST(J) + 1

END
FOR O=J+1 TO NA
620 IF JJ(J)<>II(O) THEN 650
630 IF ST(O)>ST(J) THEN 650
640 ST(O)=ST(J)
650 NEXT O
660 NEXT J
670 G=0
680 FOR K=1 TO NA
690 IF G>ST(K) THEN 710
700 G=ST(K)
710 NEXT K
720 FOR I=1 TO NA
730 IF DUR(I)=0 THEN 740 ELSE 750
740 LET SEQUA(I)=ST(I):GOTO 760
750 LET SEQUA(I)=ST(I)-1
760 NEXT I
770 FOR I=1 TO NA
780 PRINT " SEQUENCE STEP OF ACTIVITY ": I ; " ; SEQUA(I)
790 NEXT I
800 PRINT:PRINT
810 NEXT I
820 FOR I=1 TO NA
830 IF SEQUA(I)<NO THEN 850
840 LET NO=SEQUA(I)
850 NEXT I
860 PRINT " THERE ARE ";NO;" SEQUENCE STEPS IN THIS ARROW DIAGRAM":PRINT :PRINT
870 INPUT " PRESS enter KEY TO CONTINUE ";A$:CLS
880 REM ----------------------- ------------------
890 FOR I=1 TO NA:ES(C)=O:NEXT I
900 REM ** EARLY START ( FORWARD PASS COMPUTATION) **
910 REM ----------------------- -------------------
920 FOR K=1 TO NA : ES(K)=O : NEXT K
930 REM ** EARLY START ( FORWARD PASS COMPUTATION) **
940 FOR O=K+1 TO NA
950 IF JJ(K)<>II(O) THEN 980
960 IF ES(O)>ES(K) THEN 980
970 ES(O)=ES(K)
980 NEXT O
990 NEXT K
1000 E=0
1010 REM * FIND THE MAXIMUM *
1020 REM ----------------------- -------------------
1030 FOR K=1 TO NA
1040 REM
1050 IF E>ES(K) THEN 1070
1060 E=ES(K)
1070 NEXT K
1080 REM ** LATE START (BACKWARD PASS COMPUTATION) **
1090 REM ----------------------- -------------------
1100 FOR K=1 TO NA : LS(K)=E : NEXT K
1110 REM
1120 FOR L=1 TO NA : K=NA-L+1
1130 FOR O=1 TO NA-L
1140 IF II(K)<>JJ(O) THEN 1170
1150 IF LS(K)-DUR(K)>LS(O) THEN 1170
1160 LS(O)=LS(K)-DUR(K)
1170 NEXT O
1180 NEXT L
1190 REM
1200 B=1
1210 CYCLE=1
1220 REM ** TOTAL FLOAT **
1230 REM
1240 K=0
1250 FOR K=1 TO NA
1260 TF(K)=LS(K)-ES(K) : REM ** "TFij = LFij - EFij " (<>) "LSij - ESij" **
1270 NEXT K
1280 NEXT I
1290 NEXT J
1300 NEXT K
1310 NEXT O
1320 NEXT L
1330 END
IF JJ(K)=JJ(NA) THEN TF=LS(NA) : REM *** LS(NA)=ES(NA) ***

FOR K=1 TO NA
1300 IF JJ(K)=II(K) THEN TF=ES(K)-DUR(K) : REM *** ES(K)=EF ***
1310 NEXT K

FREE FLOAT

*** FREE FLOAT ***

NEXT K

BACK FLOAT ***

FOR K=1 TO NA
1380 IF II(K)=II(1) THEN TB=ES(1)-DUR(1)
1400 LET TB=ES(1)-DUR(1)
1410 FOR K=1 TO K
1420 IF II(K)<JJ(K) THEN 1450
1430 IF ES(K)<TB THEN 1450
1440 LET TB=ES(K)
1450 NEXT K
1460 LET BF(K)=(ES(K)-DUR(K))-TB
1470 NEXT K

TT=LS(NA) ; REM *** DURATION OF THE PROJECT ***

PRINTING OF THE TABLE

FOR K=1 TO NA : REM *** SEQUENCE STEP (i) ***
1570 FOR D=1 TO TT
1580 IF D=1 THEN PRINT "THE DURATION OF THE PROJECT IS ";TT;" DAYS"
1590 PRINT ; PRINT ; PRINT " THE DURATION OF THE PROJECT IS ";TT;" DAYS"
1600 PRINT ; PRINT ; PRINT " THE DURATION OF THE PROJECT IS ";TT;" DAYS"
1610 PRINT ; PRINT ; PRINT " THE DURATION OF THE PROJECT IS ";TT;" DAYS"
1620 ON CYCLE GOTO 1640,1630
1630 FOR I=1 TO NA : LET FF(I)=BF(I) : NEXT I
1640 ON B GOTO 1680,1650
1650 RETURN

RESOURCES LEVEL FOR EACH DAY

DIM SEQNO(N),LEV(TT),MO(NQ),NA(A),IQF(NO,NA),MAG(NA(NO),IQF(TT)

RESOURCE LEVEL FOR EACH DAY

 REM *** RESOURCE LEVEL FOR EACH DAY ***

LEVMAX=0

FOR D=1 TO TT
1720 LEV(D)=0
1730 K=0
1740 FOR K=1 TO NA
1750 IF ES(K)<D AND D<=ES(K)+DUR(K) THEN 1770
1760 GOTO 1780
1770 LEV(D)=LEV(D)+R(K)
1780 NEXT K
1790 PRINT "RESOURCE LEVEL OF DAY ";D;" IS ";LEV(D)
1800 NEXT D
1810 LEVMAX=0
1820 FOR D=1 TO TT
1830 IF LEV(D)<LEVMAX THEN 1850
1840 LET LEVMAX=LEV(D)
1850 NEXT DO
1860 PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PRINT ; PR
1890 Q=0
1900 FOR Q=1 TO NQ
1910 LET X=0
1920 FOR I=1 TO NA
1930 IF SEQUA(I)=Q THEN 1940 ELSE 1960
1940 X=X+1
1950 LET A(D,X)=I
1960 NEXT I
1970 LET NAQ(D)=X
1980 NEXT Q
1990 Q=0
2000 FOR Q=1 TO NQ
2010 PRINT "THERE ARE ";NAQ(D);" ACTIVITIES ON SEQUENCE STEP ";Q
2020 NEXT Q
2030 PRINT : INPUT " PRESS enter KEY TO CONTINUE";A$ : CLS
2040 REM *** BEGINNING OF THE FOWARD CYCLE ***
2050 REM -----------------------------
2060 LET CYCLE=1
2070 ON CYCLE GOTO 2080,2100
2080 FOR Q=0 TO 1 STEP -1
2090 GOTO 2120
2100 Q=0
2110 FOR D=1 TO NA
2120 Y=0
2130 LET KM=1
2140 PRINT "
2150 FOR Y=1 TO NAQ(D)
2160 REM
2170 IF FF(A(Q,Y))=0 THEN 2180 ELSE 2190
2180 PRINT :PRINT "THE FREE FLOAT OF ACTIVITY ";A(Q,Y);" IS = 0 ";: PRINT: GOTO 2670
2190 IF R(A(Q,Y))=0 THEN 2200 ELSE 2290
2200 PRINT: PRINT " THE RESOURCE RATE OF ACTIVITY ";A(Q,Y);" IS = 0 ";: PRINT
2210 PRINT "ACTIVITY ";A(Q,Y);" IS SHIFTED TO ITS FREE FLOAT LIMIT ";: PRINT
2220 ON CYCLE GOTO 2230,2240
2230 LET ES(A(Q,Y))=ES(A(Q,Y))+FF(A(Q,Y)): GOTO 2250
2240 LET ES(A(Q,Y))=ES(A(Q,Y))-FF(A(Q,Y))
2250 FOR J=1 TO NA : LET ES(J)=ES(J)+DUR(J): LET LS(J)=LS(J)+DUR(J): NEXT J
2260 GOSUB 3560
2270 E=2 : GOSUB 12
2280 GOTO 2670
2290 REM ** COMPUTATION OF THE IMPROVEMENT FACTOR "IPF" FOR EACH ACTIVITY **
2300 REM ************************************************************
2310 PRINT "
2320 PRINT "VALUES OF THE IMPROVEMENT FACTOR FOR EACH SHIFT "
2330 FOR S=1 TO FF(A(Q,Y))
2340 REM *** DETERMINE SUMX, SUMY, & M ***
2350 LET M=S : IF M >= DUR(A(Q,Y)) THEN LET M=DUR(A(Q,Y)) : GOTO 2380
2360 REM IF M>ES(A(Q,Y))+DUR(A(Q,Y)) THEN LET M=ES(A(Q,Y))+DUR(A(Q,Y))
2370 GOTO 2380
2380 SUMX=0 : SUMW=0
2390 U=0
2400 FOR U=1 TO M
2410 ON CYCLE GOTO 2450,2420
2420 SUMW=SUMW+LEV(ES(A(Q,Y))-U+1)
2430 SUMX=SUMX+LEV(ES(A(Q,Y))+DUR(A(Q,Y))-U+1)
2440 GOTO 2470
2450 SUMW=SUMW + LEV(ES(A(Q,Y))+DUR(A(Q,Y)))+U
2460 SUMX=SUMX + LEV(ES(A(Q,Y)))+U
2470 NEXT U
2480 LET IFO(S)=R(A(Q,Y))*(SUMX-SUMW-M*IQA(Q,Y))
2490 PRINT " 
2500 NEXT S
2510 PRINT
2520 S=1
2530 LET MO(Q,Y)=1
---
FOR S=2 TO FF(A(Q,Y))
IF IF0(S)<IF0(MO(Q,Y)) THEN 2570
NEXT S
LET MO(Q,Y)=S
NEXT Y

LET IFP(Q,Y)=IF0(MO(Q,Y))
PRINT "THE IMPROVEMENT FACTOR FOR ACTIVITY \"A(Q,Y)\" IS \"IFP(Q,Y)\""
PRINT :INPUT "PRESS enter KEY TO CONTINUE";A$ :CLS

---

REM : SELECT ACTIVITY WITH THE LARGEST IMPROVEMENT FACTOR :
---

IF FF(A(Q,KM))=0 OR R(A(Q,KM))=0 THEN IFP(Q,KM)=-1000000!
IF FF(Q,Y) < IFP(Q,KM) THEN 2670
LET KM=Y
NEXT Y

LET IPMAX=IFP(Q,KM)

REM : SHIFTING

PRINT "ACTIVITY \"A(Q,KM)\" HAS THE LARGEST IMPROVEMENT FACTOR ON"
PRINT STEP "A"
PRINT " THIS FACTOR IS EQUAL TO \"IPMAX : PRINT"

REM : SHIFTING

IF MO(Q,KM) > FF(A(Q,KM)) THEN LET MO(Q,KM)=FF(A(Q,KM)) : GOTO 2940
PRINT "ACTIVITY \"A(Q,KM)\" ON SEQUENCE STEP \"Q\" WILL BE SHIFTED ";MO(Q,KM) ; DAYS " :PRINT :INPUT "PRESS enter KEY TO CONTINUE";A$
FOR D1=1 TO TT
ON CYCLE GOTO 3000,2980
IF D1> ES(A(Q,KM)) - MO(Q,KM) AND D1 <= ES(A(Q,KM))+DUR(A(Q,KM))-MO(Q,KM)
THEN 3010 ELSE 2990
IF D1> ES(A(Q,KM)) AND D1 <= ES(A(Q,KM))+DUR(A(Q,KM)) THEN 3030 ELSE 3040
IF D1> ES(A(Q,KM)) AND D1 <= ES(A(Q,KM))+MO(Q,KM) AND D1 <= ES(A(Q,KM))+MO(Q,KM)+DUR(A(Q,KM))
THEN 3010 ELSE 3020
LEV(D1)=LEV(D1)+R(A(Q,KM)) : GOTO CYCLE 3020,2990
IF D1> ES(A(Q,KM)) AND D1 <= ES(A(Q,KM))+DUR(A(Q,KM)) THEN 3030 ELSE 3040
LEV(D1)=LEV(D1)-R(A(Q,KM))
NEXT D1

GOSUB 3350
*** UPDATING "ES" & "EF" ***

IF MO(Q,KM)<0 THEN 3080 ELSE 3140
ON CYCLE GOTO 3090,3100
LET ES(A(Q,KM))=ES(A(Q,KM))+MO(Q,KM): GOTO 3110
LET ES(A(Q,KM))=ES(A(Q,KM))-MO(Q,KM)
FOR J=1 TO NA : LET ES(J)=ES(J)+DUR(J) : LET LS(J)=LS(J)+DUR(J) : NEXT J
3120 GOSUB 3650
3130 B=2 : GOSUB 1220 : GOTO 2120
3140 IF CYCLE =1 THEN 3170 ELSE 3150
3150 NEXT D
3160 GOTO 3180
3170 NEXT D
3180 REM

3190 PRINT "THE VALUES OF THE RESOURCE LEVEL FOR EACH DAY, AFTER LEVELING IS "
3200 FOR D1=1 TO TT
3210 PRINT "DAY ";D1;" RESOURCE LEVEL = ";LEV(D1)
3220 NEXT D1
3230 ON CYCLE GOTO 3240,3320
3240 REM *** BEGINNING OF BACKWARD CYCLE ***
3250 PRINT: PRINT " THIS IS THE END OF THE FORWARD CYCLE "
3260 PRINT: INPUT " PRESS enter KEY TO CONTINUE "; D$:CLS
3270 PRINT: PRINT " BEGINNING OF THE BACKWARD CYCLE ":
3280 FOR I=1 TO NO
3290 FOR J=1 TO NA(I) : LET FF(A(I,J))=BF(A(I,J)) : NEXT J
3300 NEXT I
3310 LET CYCLE=2 : GOTO 2070
3320 END
3330 REM *** DRAWING OF THE HISTOGRAM OF THE RESOURCE LEVELS ***
3340 REM
3350 CLS
3360 SCREEN 1,0,0,0
3370 COLOR 9,0
3380 WINDOW (0,-1)-(TT,LEVMAX+1)
3390 FOR DO=1 TO TT
3400 LINE (DO-1,0)-(DO,LEV(DO)),2,BF
3410 LINE (DO-1,0)-(DO-1,LEV(DO)),3
3420 LINE (DO,LEV(DO))-(DO,LEV(DO)),3
3430 LINE (DO,LEV(DO))-(DO,0),3
3440 NEXT DO
3450 LINE (0,0)-(TT,0),3 : LINE (0,0)-(0,LEVMAX),3
3460 FOR LV=1 TO LEVMAX : PSET (0,LV),1 : NEXT LV
3470 FOR DO=1 TO TT
3480 PSET (DO,0),1
3490 NEXT DO
3500 INPUT "PRESS enter KEY TO CONTINUE ";C$
3510 CLS
3520 SCREEN 0,0,0,0
3530 WIDTH 80
3540 RETURN
3550 REM *** UPDATING " LS" ***
3560 FOR K=1 TO NA
3570 IF ES(A(Q,Y)>LS(A(Q,Y)) THEN LET LS(A(Q,Y))=ES(A(Q,Y))
3580 IF II(K)<>JJ(A(Q,Y)) THEN 3610
3590 IF LS(K)<DUR(K) > LS(A(Q,Y)) THEN 3610
3600 LS(A(Q,Y))=LS(K)-DUR(K)
3610 NEXT K
3620 RETURN
3630 FOR K=1 TO NA
3640 IF ES(A(Q,KM)) > LS(A(Q,KM)) THEN LET LS(A(Q,KM))= ES(A(Q,KM))
3650 IF II(K)<>JJ(A(Q,KM)) THEN 3680
3660 IF LS(K)<DUR(K) > LS(A(Q,KM)) THEN 3680
3670 LS(A(Q,KM))=LS(K)-DUR(K)
3680 NEXT K
3690 RETURN
APPENDIX F

PROGRAM OUTPUT: RESOURCE LEVELING
ENTER INFORMATION FROM YOUR ARROW DIAGRAM

NUMBER OF ACTIVITIES (INCLUDING DUMMIES)? 7

... DEFINITION OF THE NODES ...

ENTER ACTIVITY # 1 : FROM NODE ... ? 1 TO NODE ... ? 2
WHAT IS THE DURATION OF ACTIVITY # 1 ? 4
WHAT IS THE RESOURCE RATE OF ACTIVITY # 1 ? 2

ENTER ACTIVITY # 2 : FROM NODE ... ? 1 TO NODE ... ? 4
WHAT IS THE DURATION OF ACTIVITY # 2 ? 2
WHAT IS THE RESOURCE RATE OF ACTIVITY # 2 ? 2

ENTER ACTIVITY # 3 : FROM NODE ... ? 2 TO NODE ... ? 5
WHAT IS THE DURATION OF ACTIVITY # 3 ? 2
WHAT IS THE RESOURCE RATE OF ACTIVITY # 3 ? 4

ENTER ACTIVITY # 4 : FROM NODE ... ? 2 TO NODE ... ? 3
WHAT IS THE DURATION OF ACTIVITY # 4 ? 4
WHAT IS THE RESOURCE RATE OF ACTIVITY # 4 ? 6

ENTER ACTIVITY # 5 : FROM NODE ... ? 4 TO NODE ... ? 5
WHAT IS THE DURATION OF ACTIVITY # 5 ? 1
WHAT IS THE RESOURCE RATE OF ACTIVITY # 5 ? 1

ENTER ACTIVITY # 6 : FROM NODE ... ? 3 TO NODE ... ? 5
WHAT IS THE DURATION OF ACTIVITY # 6 ? 2
WHAT IS THE RESOURCE RATE OF ACTIVITY # 6 ? 2

ENTER ACTIVITY # 7 : FROM NODE ... ? 3 TO NODE ... ? 4
WHAT IS THE DURATION OF ACTIVITY # 7 ? 0
WHAT IS THE RESOURCE RATE OF ACTIVITY # 7 ? 0

PRESS enter KEY TO CONTINUE?
SEQUENCE STEP OF ACTIVITY # 1: 1
SEQUENCE STEP OF ACTIVITY # 2: 1
SEQUENCE STEP OF ACTIVITY # 3: 2
SEQUENCE STEP OF ACTIVITY # 4: 2
SEQUENCE STEP OF ACTIVITY # 5: 3
SEQUENCE STEP OF ACTIVITY # 6: 3
SEQUENCE STEP OF ACTIVITY # 7: 3

THERE ARE 3 SEQUENCE STEPS IN THIS ARROW DIAGRAM

PRESS enter KEY TO CONTINUE?

CRITICAL PATH TABLE

<table>
<thead>
<tr>
<th>ACT.#</th>
<th>NODE</th>
<th>TIME</th>
<th>RES</th>
<th>ES</th>
<th>LS</th>
<th>TF</th>
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<th>BF</th>
<th>C.F.</th>
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THE DURATION OF THE PROJECT IS 10 DAYS

PRESS enter KEY TO CONTINUE?

RESOURCE LEVEL OF DAY 1 IS 4
RESOURCE LEVEL OF DAY 2 IS 4
RESOURCE LEVEL OF DAY 3 IS 2
RESOURCE LEVEL OF DAY 4 IS 2
RESOURCE LEVEL OF DAY 5 IS 10
RESOURCE LEVEL OF DAY 6 IS 10
RESOURCE LEVEL OF DAY 7 IS 6
RESOURCE LEVEL OF DAY 8 IS 6
RESOURCE LEVEL OF DAY 9 IS 3
RESOURCE LEVEL OF DAY 10 IS 2

PRESS enter KEY TO CONTINUE?
PRESS enter KEY TO CONTINUE?

THERE ARE 2 ACTIVITIES ON SEQUENCE STEP # 1
THERE ARE 2 ACTIVITIES ON SEQUENCE STEP # 2
THERE ARE 3 ACTIVITIES ON SEQUENCE STEP # 3

PRESS enter KEY TO CONTINUE?
*** SEQUENCE STEP 3 ***

THE FREE FLOAT OF ACTIVITY # 5 IS = 0

THE FREE FLOAT OF ACTIVITY # 6 IS = 0

ACTIVITY # 7
VALUES OF THE IMPROVEMENT FACTOR FOR EACH SHIFT

\[
\text{if } \Delta O(s) = 0 \quad s = 1
\]

THE IMPROVEMENT FACTOR FOR ACTIVITY # 7 IS 0

PRESS enter KEY TO CONTINUE?

ACTIVITY # 7 HAS THE LARGEST IMPROVEMENT FACTOR ON STEP 3

THIS FACTOR IS EQUAL TO 0

ACTIVITY # 7 ON SEQUENCE STEP 3, WILL BE SHIFTED 1 DAYS

PRESS enter KEY TO CONTINUE?

PRESS enter KEY TO CONTINUE?
### Critical Path Table

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The duration of the project is 10 days

Press enter key to continue?

### Sequence Step 3

*** THE RESOURCE RATE OF ACTIVITY # 5 IS = 0***

ACTIVITY # 5 IS SHIFTED TO ITS FREE FLOAT LIMIT

### Critical Path Table

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The duration of the project is 10 days

Press enter key to continue?

The free float of activity # 6 is = 0

The free float of activity # 7 is = 0

No more shifting takes place on step 3
*** SEQUENCE STEP 2 ***

THE FREE FLOAT OF ACTIVITY # 3 IS = 0

ACTIVITY # 4
VALUES OF THE IMPROVEMENT FACTOR FOR EACH SHIFT

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<th>Improvement Factor</th>
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THE IMPROVEMENT FACTOR FOR ACTIVITY # 4 IS 0

PRESS enter KEY TO CONTINUE?

ACTIVITY # 4 HAS THE LARGEST IMPROVEMENT FACTOR ON STEP 2
THIS FACTOR IS EQUAL TO 0

ACTIVITY # 4 ON SEQUENCE STEP 2, WILL BE SHIFTED 4 DAYS

PRESS enter KEY TO CONTINUE?
CRITICAL PATH TABLE

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THE DURATION OF THE PROJECT IS 10 DAYS

PRESS enter KEY TO CONTINUE?

*** SEQUENCE STEP 2 ***

THE FREE FLOAT OF ACTIVITY # 3 IS 0

THE FREE FLOAT OF ACTIVITY # 4 IS 0

NO MORE SHIFTING TAKES PLACE ON STEP 2

*** SEQUENCE STEP 1 ***

ACTIVITY # 1
VALUES OF THE IMPROVEMENT FACTOR FOR EACH SHIFT

if O(s) >= -8
s = 1

if O(s) >= -16
s = 2

if O(s) >= -28
s = 3

THE IMPROVEMENT FACTOR FOR ACTIVITY # 1 IS -8

PRESS enter KEY TO CONTINUE?

ACTIVITY # 2
VALUES OF THE IMPROVEMENT FACTOR FOR EACH SHIFT

if O(s) = 0
s = 1

if O(s) = 0
s = 2

if O(s) = 0
s = 3

if O(s) = 0
s = 4

if O(s) = 0
s = 5

if O(s) = 0
s = 6

if O(s) = 0
s = 7

THE IMPROVEMENT FACTOR FOR ACTIVITY # 2 IS 0

PRESS enter KEY TO CONTINUE?
ACTIVITY # 2 HAS THE LARGEST IMPROVEMENT FACTOR ON STEP 1
THIS FACTOR IS EQUAL TO 0

ACTIVITY # 2 ON SEQUENCE STEP 1, WILL BE SHIFTED 7 DAYS
PRESS enter KEY TO CONTINUE?

PRESS enter KEY TO CONTINUE ?

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THE DURATION OF THE PROJECT IS 10 DAYS

PRESS enter KEY TO CONTINUE ?
*** SEQUENCE STEP 1 ***

ACTIVITY # 1
VALUES OF THE IMPROVEMENT FACTOR FOR EACH SHIFT

\[
\begin{align*}
&\text{if } O(s) = -12 \quad s = 1 \\
&\text{if } O(s) = -24 \quad s = 2 \\
&\text{if } O(s) = -36 \quad s = 3 \\
&\text{if } O(s) = -52 \quad s = 4
\end{align*}
\]

THE IMPROVEMENT FACTOR FOR ACTIVITY # 1 IS \(-12\)

PRESS enter KEY TO CONTINUE?

THE FREE FLOAT OF ACTIVITY # 2 IS \(0\)

SINCE THE MAXIMUM IMPROVEMENT FACTOR IS \(< 0\): IPMAX=\(-12\) NO SHIFTING TAKES PLACE ON THIS STEP

PRESS enter KEY TO CONTINUE?

THE VALUES OF THE RESOURCE LEVEL FOR EACH DAY, AFTER LEVELING IS

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THIS IS THE END OF THE FORWARD CYCLE

PRESS enter KEY TO CONTINUE?
BEGINNING OF THE BACKWARD CYCLE

*** SEQUENCE STEP 1 ***

THE FREE FLOAT OF ACTIVITY # 1 IS = 0

ACTIVITY # 2
VALUES OF THE IMPROVEMENT FACTOR FOR EACH SHIFT
if O(s) = 0 s = 1
if O(s) = 0 s = 2
if O(s) = 0 s = 3
if O(s) = 0 s = 4
if O(s) = 0 s = 5
if O(s) = 0 s = 6
if O(s) = 0 s = 7

THE IMPROVEMENT FACTOR FOR ACTIVITY # 2 IS 0

PRESS enter KEY TO CONTINUE?

ACTIVITY # 2 HAS THE LARGEST IMPROVEMENT FACTOR ON STEP 1
THIS FACTOR IS EQUAL TO 0

ACTIVITY # 2 ON SEQUENCE STEP 1, WILL BE SHIFTED 7 DAYS

PRESS enter KEY TO CONTINUE?

PRESS enter KEY TO CONTINUE?
CRITICAL PATH TABLE

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THE DURATION OF THE PROJECT IS 10 DAYS

PRESS enter KEY TO CONTINUE?

*** SEQUENCE STEP 1 ***

THE FREE FLOAT OF ACTIVITY # 1 IS = 0

THE FREE FLOAT OF ACTIVITY # 2 IS = 0

NO MORE SHIFTING TAKES PLACE ON STEP 1

*** SEQUENCE STEP 2 ***

THE FREE FLOAT OF ACTIVITY # 3 IS = 0

ACTIVITY # 4

VALUES OF THE IMPROVEMENT FACTOR FOR EACH SHIFT

\[ \begin{align*}
\text{if } O(s) = -12 & \quad s = 1 \\
\text{if } O(s) = -28 & \quad s = 2 \\
\text{if } O(s) = -28 & \quad s = 3 \\
\text{if } O(s) = -28 & \quad s = 4 \\
\end{align*} \]

THE IMPROVEMENT FACTOR FOR ACTIVITY # 4 IS -12

PRESS enter KEY TO CONTINUE?

SINCE THE MAXIMUM IMPROVEMENT FACTOR IS < 0 : IPMAX=-12

NO SHIFTING TAKES PLACE ON THIS STEP

PRESS enter KEY TO CONTINUE?
THE RESOURCE RATE OF ACTIVITY # 5 IS = 0

ACTIVITY # 5 IS SHIFTED TO ITS FREE FLOAT LIMIT

**CRITICAL PATH TABLE**

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THE DURATION OF THE PROJECT IS 10 DAYS

PRESS enter KEY TO CONTINUE?

THE FREE FLOAT OF ACTIVITY # 6 IS = 0

ACTIVITY # 7 VALUES OF THE IMPROVEMENT FACTOR FOR EACH SHIFT

if(0<s)= 0  s= 1

THE IMPROVEMENT FACTOR FOR ACTIVITY # 7 IS 0

PRESS enter KEY TO CONTINUE?

ACTIVITY # 7 HAS THE LARGEST IMPROVEMENT FACTOR ON STEP 3

THIS FACTOR IS EQUAL TO 0

ACTIVITY # 7 ON SEQUENCE STEP 3, WILL BE SHIFTED 1 DAYS

PRESS enter KEY TO CONTINUE?
PRESS enter KEY TO CONTINUE?

CRITICAL PATH TABLE

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THE DURATION OF THE PROJECT IS 10 DAYS

PRESS enter KEY TO CONTINUE?
*** SEQUENCE STEP 3 ***

THE FREE FLOAT OF ACTIVITY # 5 IS = 0

THE FREE FLOAT OF ACTIVITY # 6 IS = 0

THE FREE FLOAT OF ACTIVITY # 7 IS = 0

NO MORE SHIFTING TAKES PLACE ON STEP 3

THE VALUES OF THE RESOURCE LEVEL FOR EACH DAY, AFTER LEVELING IS

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OK
REFERENCES


