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STOCHASTIC ASPECTS IN PROJECT MANAGEMENT

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TO MY MOTHER,
SISTERS AND BROTHERS

ACKNOWLEDGEMENT

I would like to express my deep acknowledgment to prof. Arun Walvekar for his valuable support and supervision which accompanied the progress of this research.

I am very grateful to Dr. Majed Dabbas and Dr. Ghaleb Abbasi for their kind participation in this work and encouragement.

Best regards to all friends for their great efforts and feelings.

الخلاصة

مظهرين رئيسين من المظاهر العشوائية المصاحبة لبرمجة المشاريع تمت دراستها ومعالجتها في هذا البحث. المظهر الأول هو الاحتمالية المصاحبة للوقت اللازم لانهاء أي نشاط من نشاطات المشروع، أما المظهر الثاني فهو الاحتمالية المصاحبة لوقت توفر المورد (من معدات، مواد، وأيدي عاملة)، حيث أن هناك عدة عوامل تم مناقشتها في هذا البحث قد تؤدي الى عدم التأكد من وقت توفر المورد.

وقد تم دراسة هذين المظهرين مع وجود عائق شحة الموارد المتوفرة، لذا يقدم هذا البحث الحلول المناسبة والمنطقية لمعظم المشاريع الانشائية والصناعية التي كثيرا ما اتصفت مشاريعها بتلك الخصائص.

في هذه الاطروحة استخدم مدخل رياضي لتحويل قيم الثلاثة أوقات المتنبأ بها (الوقت التفاؤلي، الوقت الأكثر احتمالية، والوقت التشاؤمي) سواء كانت لزمن النشاط أو لزمن المورد، إلى اقتران بيتا BETA الاحتمالي بدلا من استخدام معاملات بيرت PERT.

وقد تم معالجة هذه المظاهر باستخدام برنامج حاسوب تم انجازه من خلال هذا البحث. ويعتمد هذا البرنامج على محاكاة مونتوكارلو التي يمكن تعريفها على أنها الطريقة التي يتم من خلالها اختيار الارقام عشوائيا من اقتران توزيع احتمالي واحد او اكثر لكي يتم استخدامها في محاكاة دراسة معينة. وتستخدم هذه المحاكاة في العادة عندما تفشل الحلول الرياضية لمشكلة معينة او عندما تصبح هذه الحلول غير عملية.

يقوم البرنامج بعمل تحليل احصائي وآخر اقتصادي لوقت انهاء المشروع. حيث يقوم البرنامج بحساب معدل انهاء المشروع وانحرافه المعياري وبحساب تكاليف المشروع المصاحبة لقيم احتمالية مختلفة لانجاز المشروع. يمكن الاستفادة من هذه النتائج في الحصول على اقل كلفة ممكنة للمشروع مرافقة لاحتمالية معينة لانجاز المشروع. هذه الاحتمالية تحدد من ذوي متخذو القرار في المشروع. وكذلك يمكن اعتماد كلفة المشروع الناتجة على أنها السعر المناسب لعطاء هذا المشروع وذلك في مرحلة تسعير العطاء.

بالاضافة الى التحليل الاحصائي والاقتصادي الذي ينجزه هذا البرنامج فإنه يقوم بجدولة جميع نشاطات المشروع وذلك بتحديد تاريخ بداية ونهاية أي نشاط.

ABSTRACT

Some of the stochastic aspects of project scheduling management are addressed in this research. These aspects are the uncertainty associated with the activity duration and the uncertainty associated with resource availability. Both aspects are common in most of real life projects.

The research aims to develop a computer-based-project scheduling model incorporating the two stochastic aspects. This model enables the managers to analyze the actual conditions facing their projects, and to avoid making assumptions leading to unfavorable results.

Monte Carlo simulation is adopted to achieve the research objective. It is found to be an efficient tool for solving stochastic project scheduling. Mathematical approach is used to fit the three time estimates of both activity duration time and resource availability, instead of using PERT parameters.

The software developed within this research is user-friendly and self explanatory. It gives the user valuable cost and statistical analysis of the completion time of the project the software generates twelve alternatives of solving the problem. The obtained cost for each alternative at different performance probabilities, enables the user to minimize the cost of the project. Also the obtained results may be used in bidding purposes.

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CHAPTER ONE

INTRODUCTION

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INTRODUCTION

A project can be defined as a group of interrelated activities that must be executed in a specific order to achieve a certain goal. Project management involves the coordination of groups of activities wherein the manager plans, organizes, staffs, directs and controls to achieve the project objective abiding to constraints on time, cost, and performance of the end product [1].

Over the years, a number of techniques have been developed to assist the manager in planning, scheduling and controlling his/her projects. Two of the most important techniques are the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT).

Although CPM and PERT techniques have been developed independently, both have used the network as the graphical model and their solutions identify the longest, or critical, path in terms of project duration.

The major difference between PERT and CPM is related to the activity duration time. PERT explicitly takes account of the uncertainty in the activity duration estimates; this has been achieved by specifying three estimates for each activity duration time. In this case, the time can be considered as a random variable. This feature is common in the activities which have never been performed before, and in the absence of a great deal of information about their execution.Therefore, PERT is a statistical treatment of the uncertainty in the activity performance time, and includes an estimate of the probability of meeting a specified date.

On the other hand, CPM assumes that the duration of each activity can be established with reasonable accuracy; the variation in activity time is negligible, these activities can be considered as deterministic activities.

Unfortunately, PERT and CPM techniques assume that the available resources are unlimited, so the schedules produced may not be realistic, since most of the projects are faced with the limited resources problem. But incorporating the resource constraints complicates the scheduling process and may alter some of the basic notations of PERT/CPM techniques. Incorporating and including resource constraints on project scheduling process can be handled either by heuristic techniques or by optimization techniques.

A heuristic technique is a rule of thumb consisting of a set of decision rules that simplify the scheduling process and may lead to an optimum solution, but does not guarantee optimality.

While in the optimal techniques, mathematical approaches are used to guarantee optimal solution, but such techniques are impractical for complex and large projects which may require a great deal of time. Hence, in large projects including construction and industrial projects, heuristic techniques are more practical than the optimization techniques.

Uncertainty in the availability of the resources means that the date at which the resources will be available is uncertain and subject to a certain variation. The resources whose availabilities are uncertain are called uncertain resources, and whose availabilities are certain are called certain resources [2].

1.1 PROBLEM DEFINITION

This research involves the analysis of project scheduling by considering the following three specific problem areas:

1) *Resource constraints:-*

As stated previously, both PERT and CPM assume the availability of unlimited resources, this assumption contradicts with real-life projects. In this research, the constrained resource is considered as one aspect of the problem.

2) *Stochastic Activity Duration:-*

In CPM approach, the activity durations time are considered to be certain which may also contradict with real-life situation; in which some or all activities durations are characterized by large variances. As in PERT, the stochastic activity durations are taken into consideration in this research.

3) *Stochastic Resource Availability:-*

In real-life situation the availability of the resources may be uncertain due to different reasons studied in detail in chapter two. Therefore, to make the case more realistic, all the three specified problem domains are incorporated in project scheduling.

1.2 RESEARCH OBJECTIVE

The main objective of this thesis is to develop a computer-based-project-scheduling model incorporating the three problem domains mentioned previously (resource constraints, stochastic activity duration, and stochastic resource availability).

A simulation software program is developed within this research to find some statistical results of the project completion time. The software developed gives the manager larger flexibility in handling the two stochastic aspects as well as the resource constraints in project management. Also, this software helps the manager in his decision-making process to choose the most economical alternative. In this case, the alternatives are related to use either certain or uncertain resources.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO
LITERATURE REVIEW

2.1 THE CRITICAL PATH METHOD (CPM) [1]

CPM was developed by a group effort in 1956 by the Dupont company and Remington Rand Univak. The objective of the CPM team research was to determine how best to reduce the time required to perform routine plant overhaul, maintenance and construction work. In essence, they were interested in determining the optimum trade-off of time (project duration) and total project cost.

This objective amounts to the determination of the duration of a project which minimizes the sum of the direct and indirect costs. Direct costs include labor and materials, while indirect costs include supervision as well as cost of production time lost due to plant downtime.

CPM treats activity performance times in a deterministic manner with the ability of arriving at a project schedule which minimizes total project cost. Since the early success of CPM in the chemical and construction industries, the use and development of the critical path method have grown at a rapid rate.

Maintenance and shutdown continue to be a most productive area of application of critical path method. Some of the recent applications of CPM include the development and marketing of new products of all types such as new automobile models, food products, computer programs and complex surgical operations.

While the initial CPM used the arrow diagram, John W. Fondahl in 1961 used the precedence diagramming technique. Fondahl accepted the original basics of the critical path method, but instead of representing the activity by the link (arrow), he placed the activity on the node; so the links between the nodes explain the relationships between the activities [3].

2.2 PERT SYSTEM WITH THREE TIME ESTIMATES [1,2]

Simplicity of the single-time estimate (deterministic activity) compared with three-time estimates makes it a desirable method, but there are many places where the single-time is not applicable, as mentioned earlier, for the activity which have never performed before, it will be questionable to use the single-time estimate, and will be preferable in this case to use the three-time estimates approach.

The three-time estimates are:-

1) *The optimistic time estimate (a)*: This estimate is the shortest possible time in which the activity can be performed under optimum condition. It assumes that every thing goes well.

2) *The pessimistic time estimate (b)*: It is the longest time it might take to complete an activity, it assumes every thing goes wrong.

3) *The most likely time estimate (m):* It lies between the optimistic and the pessimistic estimates, it assumes normal condition encountered in the activity.

In general, the knowledgeable supervisory should estimate these times. The following points must be taken into consideration for the estimating process [1']:-

1) Estimates should be based on the actual or potential manpower expected to be available for each activity. It should be based upon uniform workweek, consistent with schedules and budget if available at this stage.

2) Estimates should be based upon the best present information about the technology, techniques and tools available.

3) The possibility of acts of GOD, such as fire, flood are should not be considered in the estimating.

4) The estimation of each activity should be made independently of the other activities, the estimates of one activity should not affect the others, so the central limit theorem can be applied.

5) Estimates of (a,m,b) should not be influenced by the time available to complete the project, i.e, it is not appreciated to revise estimates in times after learning that the project critical path is long. Changes can be made only if the scope of the activity is altered or when

the manpower and other facilities are changed.

2.3 STUDY OF THE ASSUMPTIONS USED IN THE ANALYSIS AND SOLUTION OF A PERT NETWORK [4]

PERT is essentially a network analysis. Between each two points in the network three-time estimates are given for completion. The two extreme points are the optimistic and the pessimistic estimates. The third is the mode of the distribution. The extreme points are assumed to be ultimate or the (0) and (100) percentages of the distribution of the time.

This time distribution is estimated by the beta distribution and is defined by the following formula:-

$$f(t) = k.\ (t-a)^{\alpha}.(b-t)^{\beta}$$

Where a and b are pessimistic and optimistic time respectively. The mean of the distribution is assumed to be (a+4m+b)/6, and the standard deviation is given by (b-a)/6. It should be pointed out that the true distribution of the activity duration time is unknown, so all of the above equations are approximated values.

Due to the PERT assumptions the following types of errors may occur:

- The first error is related to the BETA distribution assumption. This error calculated between the following two extreme distributions, the first if the true distribution is uniform and the second if it is a pure delta one.

The worst error in the mean equals 1/3 (2m-1) and the worst error in the standard deviation equals 1/6.

- The second type of error is related to the difference between the actual parameters and the assumed parameters, since the actual mean = $(\alpha+1)/(\alpha+\beta+2)$, the actual mode = $\alpha/(\alpha+\beta)$ and the actual standard deviation = $[(\alpha+1)/(\alpha+\beta+2)^2.(\alpha+\beta+3)]^{1/2}$.
- The third type of error is related to the method used to find the project completion time, the mean of the project completion calculated by PERT is never greater than the true mean and its standard deviation is usually greater than the actual standard deviation [5].

A seminar, as part of the requirements of M.Sc. programme in the Industrial Engineering Department at the University of Jordan was performed by the writer in 1991 under the supervision of prof. B. Mahagan. The objective of the seminar was to show the difference between the mean and standard deviation of the project completion time obtained by PERT and simulation using GPSS (General Purpose Simulation System).

Five different project networks were analyzed by the two prescribed approaches. The results are summarized in table (2.1).

The seminar revealed that the mean of the completion time of the project obtained by PERT is smaller than the mean obtained by simulation technique, and the difference between the two means increases as number of critical path increase.

And the standard deviation obtained by PERT usually greater than the standard deviation obtained by simulation.

Table (2.1)

NETWORK	PERT PARAMETERS		SIMULATION PARAMETERS		% OF ERROR	
	μ	σ	μ	σ	$\%\mu$	$\%\sigma$
Two parallel critical paths	37.660	2.198	39.422	2.1275	4.5	3.3
Three parallel critical paths	37.660	2.198	40.084	1.9107	6.0	15.0
Three paths of unequal length	41.003	1.394	41.394	1.6040	0.87	13.0
Three critical paths with cross connecting	49.930	2.833	51.188	2.1530	2.6	31.0
Generall network with one critical path	53.493	2.692	53.620	2.3370	0.2	15.0

2.4 RESOURCE CONSTRAINTS IN PROJECT SCHEDULING [1,5,6,7]

In recent years, constraints resource management has received more attention, since all projects need resources to carry out their activities. Usually, these resources are limited and a high utilization value of such resources must be achieved.

Scheduling projects with resource constraints can be divided into the following two groups:-

1) *Resource Leveling:-* is the process where the activities in the network are scheduled such that the project resources

are minimized on a day-to-day basis, the project is restricted by a specific due date while the available resources are sufficient. Resource Leveling aims at achieving two objectives: the first is to meet the physical limits of the resource, the second is to avoid the fluctuation of the demand of the resource from day to day and to level the demand as much as possible through the duration of the project [1].

2) *Fixed Resource Limits Scheduling* [1,5]:- In this case there are a definite limitations on the available resource, the aim of this process is to minimize the project duration subjected to the fixed limits on resource availability.

Project duration may increase beyond the duration determined by the conventional CPM calculations which implicitly assume unlimited availability of resources.

The basic general approach of the two categories are similar and summarized by arranging the activities according to the predetermined criteria and scheduling them as soon as their predecessors are completed and adequate resources are available.

The fixed-resource-limits schedule uses the concept of resource leveling, and only the limited resource is studied in this literature review. There are two approaches for solving the limited resource problem, either by a heuristic approach or by the optimizing approach.

2.4.1 HEURISTIC APPROACH IN THE RESOURCE CONSTRAINTS [5,7]

Two different categories of heuristics have been found to be most effective in minimizing project duration [7]:-

1) Heuristics incorporating some measures of time such as minimum slack rule.
2) Heuristics incorporating some measures of resource usage.

Some of the heuristics rules of both categories are explained below:-

2.4.1.1 ROT rule

ROT was developed by Elsayed [7]. ROT stands for Resource Over Time and used for a single type of resource project scheduling. The ROT value can be calculated by replacing the duration time of each activity on the network by the ratio of the resource over time, and the length of the critical path of each activity is found (being the starting node of the activity under consideration as the network starting node.)

Then the activities are arranged in decreasing order according to their ROT values (the activity with a larger ROT value has the priority to be scheduled).

1.4.1.2 Actim Criterion

ACTIM (Activity Time) criterion is similar to the ROT criterion except for ranking of the activities is based on the value of the maximum time which the activity controls in the network (the length of the critical path for the activity, being its starting node as starting node for the network). The activities are arranged according to their actim value in decreasing order, and the priority of scheduling is given for the activity which has high actim value.

2.4.1.3 Minimum Job Slack (MINSLK) criterion

In this algorithm the priority is given to the activity with minimum slack (total float) which is equal to the difference between the late finish and the early finish dates, or the difference between the late start and the early start dates [7].

2.4.1.4 Resource Scheduling Method (RSM) [7]

This rule was developed by Brand, Meter and Shaffer at the university of Illinois. Activity priority is calculated as follows:-

Give precedence to the activity with the minimum value of d_{ij}, where d_{ij}= increase in project duration resulting when activity j follows activity i =

$$\max (0; (EFT_i - LST_j))$$

where EFT_i= the early finish time of activity i

LST_j= the late start time of activity j

2.4.1.5 Minimum Late Finish Time (LFT)

The priority among the activities in the conflicts set is given to the activity which has minimum late finish time. It was developed by Pascoe, Muller and Gonguet.

2.4.1.6 Greatest Resource Demand (GRD) [7]

It assigns priority on the basis of total resource unit requirements of all types, the higher the GRD the higher the priority given.

Activity priority is calculated as:

$$\text{priority} = d_j \sum_{i=1}^{m} r_{ij} \quad \text{where:-}$$

d_j = duration of activity j

r_{ij} = requirement resource of type i for activity j

m = number of different resource types.

2.4.1.7 Greatest Resource Utilization (GRU)

This rule gives priority to the combination of activities which results in maximum resource utilization in each scheduling interval (minimum idle resources). The rule is implemented by solving a zero-one integer programming problem. This rule was found to be as in effective as MINSLK rule [7].

2.4.1.8 Shortest Imminent Operation (SIO)

This rule gives priority on the basis of shortest activity duration time.

2.4.1.9 Most Job Possible (MJP)

It gives priorities to that combination of activities which results in the greatest number of activities being scheduled in any time interval. It is also solved by a zero-one integer programming.

2.4.1.10 Select Job Randomly (RND)

Select job randomly assigns priorities for jobs in a purely random basis.

Studies in the effectiveness of the heuristics methods [2] have shown that there is no heuristic rule which produces the optimal results for all problems, the heuristics which give good results (minimum project duration) for a certain problem may give poor results for other problems.

In 1975 Edward W.D. [7] tackled the last eight heuristics mentioned above, and tested them against eighty-three different multi-resource project networks, the results were compared with the optimal solutions. His research showed that the MINSLK rule produced the best performance among the eight rules; the solutions of twenty-four out of the eighty-three problems were optimal, and on average the project duration for the eighty-three problems was 5.6% above the optimal solution.

RSM and LFT rules were close in their performance to MINSLK rule and these three rules combined produced generally better results than the other five.

None of the previous heuristic rules addressed the stochastic activity durations or the uncertainty in the availability of the resources.

In 1985 Adedji B. Bair [6] presented a computer-based project scheduling heuristics, named STARC (Stochastic Time And Resource Constraints). The heuristics explicitly address the stochastic activity durations. In his research a mathematical procedure using the three PERT time estimates and the theoretical properties of the beta distribution was developed for modeling a beta distribution for each activity. The distribution is used in generating random observations that serves as an activity duration in the scheduling process.

In 1983 Hira, N.A. [2] addressed the problem of the uncertainty in the availability of resources. Hira developed a new model called REM (Risk Evaluation Model). There are many factors affecting the uncertainty of resource availability, some of them are [2]:

1. *Uncertainty in releasing resources from ongoing projects:* The contractor's own resources are generally tied-up by his ongoing project, and may not be available at a certain date due to various elements in the construction environment, such as weather condition, labor strikes, and variation in productivity.
2. If the company resources are rented to other companies, getting hold of these resources are subject to uncertainty.
3. If the required resources are going to be purchased, their delivery by the vendor and the manufacturer may be

uncertain.

Due to these uncertainties, the number of resources available as well as the date on which they will be available are uncertain. But REM cannot be applied to a project with probabilistic duration and only considers certain or uncertain type of resource availability [2].

CHAPTER THREE

FUNDAMENTALS OF PROJECT MANAGEMENT

CHAPTER THREE

FUNDAMENTALS OF PROJECT MANAGEMENT

3.1 NETWORKS

The heart of CPM/PERT approaches is a network representation of the elements of the Project. The arrangement and shape of the network has no effect on the scheduling process, but shows the interdependencey and the precedence relationships among the activities.

The idea of using the network is not new, it started with the beginning of the CPM/PERT at the end of 1950's. It was an extension for the GANTT (BAR) chart developed by Henry L.GANTT during the world war I.

The network consists of two basic elements, nodes (events) and arrows between these nodes. There are two types of networks, the first called Activity on arrow (AOA), where the arrow represents the Activity and symbolized by the numbers of the nodes connected by the arrow. The second type called Activity on node (AON), where the node represents the Activity symbolized by the node number.

The following terms and symbols used in the network analysis:-

1. ACTIVITY:-

Is a unique unit in the project distinguished by prescribed limits of time, or any task, function, or decision which consumes time [3].

2. ARROW:-

A graphical representation of an activity, represented by a line connecting two nodes, having a head at one tail. The length of the arrow has nor significance, while the relative position of these arrows has a great significance.

3. NODE:-

A geometric shape like circle, square...etc, node may be considered as time points where the activities may be scheduled.

4. DUMMY ACTIVITIES:-

An activity which needs neither time nor resources, its purpose is to show a precedence relationship in aspecial situation, represented by a dashed line.

5. PREDECESSOR ACTIVITY:-

Is the activity which immediately proceeds the one being considered. In figure(1) Activities (1-3) & (2-3) are predecessors for activity (3-4).

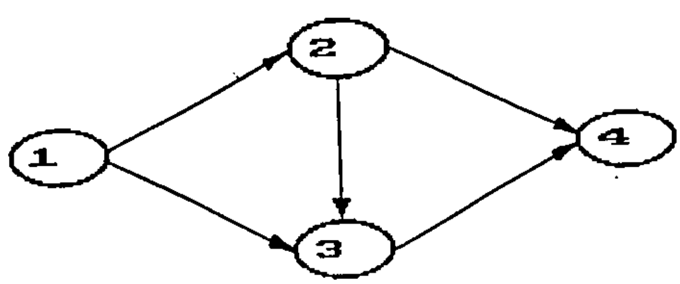


FIG (1)

6. SUCCESSOR ACTIVITY:-

Is the one which immediately follows the one being considered. In figure (1) Activity (3-4) is a successor activity for activities (1-3) & (2-3).

7. MERGE POINT:-

A point at which two or more activities are predecessors to a single activity. Point 3 in figure (1) is a merge point.

8. BURST POINT:-

A point at which two or more activities are successors to a single activity. Point 2 is a burst point.

The following rules should be considered in drawing the network:-

1. The network has only one starting and ending nodes.
2. All nodes except the starting node, should have at least one predecessor.
3. All nodes except the terminal node, should have at least one successor node.
4. The length of the arrow has no correlation to the activity duration time, its direction from left to right, and its relative position specifies the precedence relationship.

3.2 CPM APPROACH

The main purpose of the CPM analysis is to locate the critical path(s) or the critical activities. Critical path can be defined as the longest path in the network, and its associated time is the minimum time required to complete the project.

The following four time values should be defined for each activity before discussing the CPM computations:-

1. *Early start time (EST):-* Which is the earliest possible time for the activity to start.
2. *Early finish time (EFT):-* Which is the EST plus the activity duration.
3. *Latest start time (LST):-* The latest possible time for the activity to start without affecting the completion time of the project.
4. *Latest finish time (LFT):-* Equal to the latest start time for the activity plus its duration.

Figure (2) shows the four time values for a hypothetical activity [3].

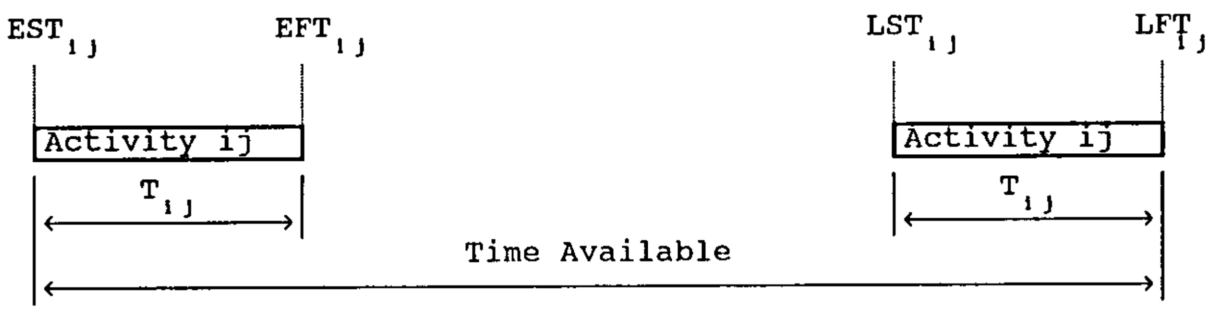


FIG (2)

CPM analysis involves two types of computations, the forward pass and the backward pass.

3.2.1 FORWARD PASS

Both the EST and EFT can be computed and the completion time of the project is found.

It starts by assuming the EST of the initial activity equals zero, and each activity starts as soon as its predecessor activities are executed.

The forward pass can be summarized as follows:-

1. Set the early start time of the initial node to be equal zero.
2. Set the EST of all activities commencing from the initial node to be equal zero.
3. The EFT of any activity equals to EST plus the duration.
4. For other activities, the EST equals to the maximum of EFT of all predecessor activities.
5. Steps 3 & 4 are repeated for all activities involved.

3.2.2 BACKWARD PASS

The LST and LFT of the activities is calculated through this pass. Also, the critical path(s), as well as the critical activities are defined.

The following algorithm describes the backward pass:

1. The LFT of the terminal node equals to the maximum EFT of all activities merging into the terminal node.

2. The LFT of all activities merging into the terminal node

equals to LFT of this node.

3. Then, the LST is calculated by subtracting the activity duration time from the LFT.

4. For any other activity the LFT is equal to the minimum LST of all its successor activities.

5. Steps 3 & 4 are repeated for all activities undergoing scheduling.

The following example shows the network drawing process and the CPM algorithm:-

Example 1.1:-

The network and the EST, EFT, LST & LFT for each activity in the project, the precedence relationships and the activities duration times for the project are shown in table 1.

Table 1

ACTIVITY	PREDECESSOR	DURATION TIME
A	-	3
B	-	5
C	A	4
D	A	2
E	B,C	2

The following arrow diagram, figure (3), is drawn using the above data.

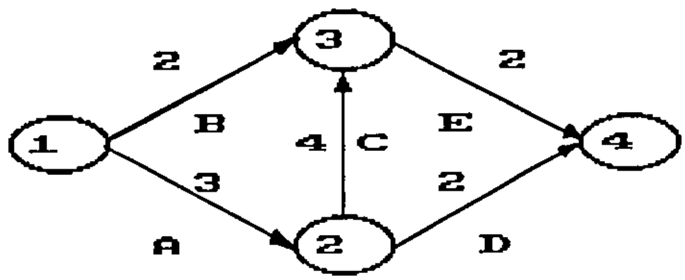


FIG (3)

Forward Pass:-

1. EST for node number (1) = zero.
2. EST for activities (1-2) & (1-3) equal to zero.
3. EFT for activity (1-2) = 0 + 3 = 3.

   EFT for activity (1-3) = 0 + 5 = 5.
4. EST for activities (2,3)&(2,4) = 3.

   EFT for activity (2,3) = 3 + 4 = 7.

   EFT for activity (2,4) = 3 + 2 = 5.
5. EST for activity time (3-4) =

   = max EFT of {(1,3) , (2,3)}

   = max (5,7) = 7.

   LFT for activity (3,4) = 7 + 2 = 9
6. EST for terminal node =

   = max EFT of {(2,4) , (3,4)}

   = max (5,9) = 9.

Backward Pass

1. EFT for terminal node equal to EST = 9.
2. LFT for activities (3,4) & (2,4) equal to LST for terminal node = 9.

LST for activity (3,4) = 9 - 2 = 7

LST for activity (2,4) = 9 - 2 = 7.

3. LFT for activities (1,3) & (2,3) =

min LST of activity (3,4) = 7

LST for (1-3) = 7 - 5 = 2

LST for (2-3) = 7 - 4 = 3.

LFT for activity (1,2) equal to min

LST of activities {(2,4) , (2,3)}

= min (7,3) = 3

ST of (1,3) = 3 - 3 = 0

The above results are summarized in Table (2).

Table 2

ACTIVITY	DURATION TIME	EST	EFT	LST	LFT
1-2	3	0	3	0	3
1-3	5	0	5	2	7
2-3	4	3	7	3	7
2-4	2	3	5	7	9
3-4	2	7	9	7	9

3.2.3 FLOAT COMPUTATIONS

There are mainly two types of floats which can be derived from the forward and backward pass computations, these are the total and free floats.

Total Float:

Is the amount of time which an activity may be delayed without affecting the completion time of the project. The amount of the total float (TF) can be calculated according to the following equation:-

$$TF_{ij} = LST_{ij} - EST_{ij} = LFT_{ij} - EFT_{ij}$$

Free Float:-

The amount of time an activity can be delayed without affecting the completion time of the project nor the early start of any successor activity. Free float (FT) can be calculated according to the following equation:-

$$FF_{ij} = \min (EST_{s}) - LFT_{ij}$$

Where ij is the number of the activity under consideration, the subscript (s) is group of successor activities of activity ij. The critical activity has a total float equals to zero.

TF and FF of the activities in the previous example can be found as follows:-

TF for activity (1-2) = $LST_{1-2} - EST_{1-2} = 0$

FF for activity (1-2) = $\min (EST_{2-3}, EST_{2-4}) - LFT_{1-2} = 0$

TF for activity (1-3) = $LST_{1-3} - EST_{1-3} = 2-0 = 2$

FF for activity (1-3) = $\min (EST_{3-4}) - LFT_{1-3} = 7 - 7 = 0$

TF for (2-3) = 7 - 7 = 0

FF for (2-3) = 9 - 9 = 0

TF for (2-4) = 7 - 3 = 4

FF for (2-4) = 9 - 9 = 0

TF for (3-4) = 0

FF for (3-4) = 0

Critical activities are {(1-2) , (2-3) , (3-4)}

3.3 PERT APPROACH

PERT Introduces uncertainty into time estimates of the activities durations and hence in the project duration. PERT Uses three time estimates (optimistic, pessimistic and most likely) and simplifies the computation by the following two assumptions:-

$$T_E = \frac{a + 4m + b}{6}$$

$$\sigma_E = \frac{b - a}{6}$$

Where TE is the expected time of the activity, σ_E is the standard deviation.

PERT proceeds in the analysis of the forward and backward pass computations using TE and σE, similar to the CPM approach.

Since the estimating process for any activity is independent to any other activity, and usually there are plenty of activities (more than 10) in the project, central limit theorem can be applied assuming the distribution of the completion time is normal, its mean equals the sum of the activities means of the critical path, and its variance equals to the sum of activities variances.

The probability of project completion at a certain scheduled time equals the area under the standard normal curve to the left of scheduled time.

The value of the standard normal equals $Z = \frac{T_s - \mu}{\sigma}$ where T_s is the scheduled time, μ the mean of the completion time, σ the standard deviation of the completion time.

Figure (4) shows the previous symbols.

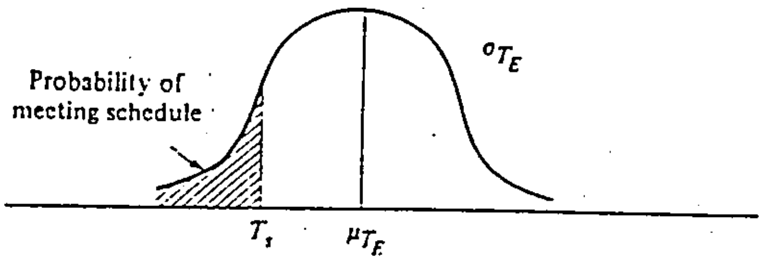


FIG (4)

3.4 RESOURCES ALLOCATION

Imposing resources restriction of some kind on project activities will lead to an increased completion time of the project. Since the activity may not be scheduled as soon as all of its predecessor are finished due to the shortage in resources which may be tied up by other activities.

Many heuristics and optimal algorithm have been developed addressing this problem. One of the heuristics which is going to be used in this research is explained here.

3.4.1 MINIMUM LATE FINISH HEURISTIC (MLF)

This heuristic gives priority in scheduling to the activity with minimum late finish. The activities are arranged in ascending order according to their late finish time (LFT).

The algorithm of resource allocation under this criterion may be summarized as follows:-

1. Compute the LFT for each activity using CPM/PERT approaches.
2. A new forward pass computations starts according to the following conditions:-

(Each activity should be scheduled if all of its predecessors have been finished and the available resources are enough to satisfy the demand by the activity, otherwise the activity should wait till new resources are released).

3.4.2 EXAMPLE

For the network in figure (5) find the EST, EFT for each activity and the completion time of the project, the amount of the resources available is 4.

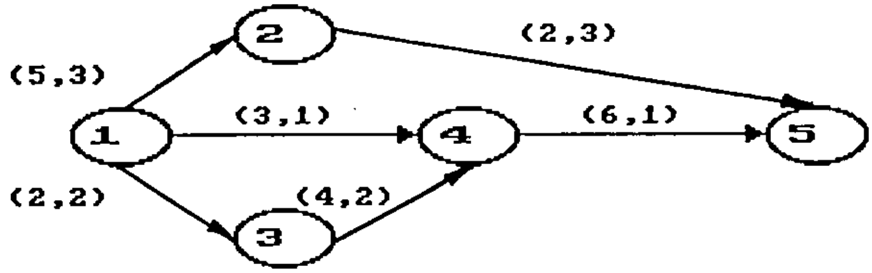


FIG (5)

The numbers between parenthesis are the activity duration time and the resources required respectively.

The results of CPM computations are summarized in table (4).

Table 4

ACTIVITY	DURATION	EST	EFT	LST	LFT	TE	FF
1-2	5	0	5	5	10	5	0
1-3	2	0	2	0	2	0	0
1-4	3	0	3	3	6	3	0
2-5	2	5	7	10	12	5	0
3-4	4	2	6	2	6	0	0
4-5	6	6	12	6	12	0	0

COMPUTATIONS UNDER RESOURCE CONSTRAINED

Activity {(1-2) , (1-3) , (1-4)} can be scheduled, but since the 4 available resources do not satisfy the demand of the three activities, the priority of the activities are arranged in the following decreasing order according to LFT criterion:-

(1-3 , 1-4 , 1-2).

At time equal to zero only activities (1-3) & (1-4) can be scheduled

EST for activity 1-3 = 0

EFT for activity 1-3 = 2

EST for activity 1-4 = 0

EFT for activity 1-4 = 3

At time equal to 2, three resources are available and activities (3-4) & (1-2) can be scheduled. Activity (3-4) has the priority over activity (1-2).

EST for activity (3-4) = 2

EFT for activity (3-4) = 6

At time = 3 , 2 resources are available activity 1-2 can't be scheduled due to the lack of the resource.

At time = 6 , 4 resources are available activity 1-2 has the priority over (4-5)

EST for activity (1-2) = 6

EFT for activity (1-2) = 11

EST for activity (4-5) = 6

EFT for activity (4-5) = 12

Activity (2-5) can be scheduled at time = 11

EST for activity (2-5) = 11

EFT for activity (2-5) = 3

The above results are shown in table (4)

Table 4

ACTIVITY	DURATION	EST	EFT
1-2	5	6	11
1-3	2	0	2
1-4	3	0	3
2-5	2	11	13
3-4	4	2	6
4-5	6	6	12

CHAPTER FOUR

FORMULATION AND ANALYSIS OF THE RESEARCH PROBLEM

CHAPTER FOUR

FORMULATION AND ANALYSIS OF THE RESEARCH PROBLEM

This chapter introduces the different aspects of the research problem, describes the methodology adopted to achieve the research objective, concerns with the analysis of the beta distribution, modeling a beta density function from the three estimates of the activity duration and the resource availability.

Different available alternatives regarding resource availability are explained and analyzed. This analysis is performed by the Monte Carlo simulation which generates the random number variable from the modeled Beta function.

Appropriate number of simulation runs (sample size) is specified. A description of the software is mentioned and an application example is solved.

4.1 THE ANALYSIS OF BETA DENSITY FUNCTION AND ITS ASSOCIATED PARAMETERS

Tackling the problem of the uncertainty in the activity duration and in the resource availability is the main concern of this research.

The exact distribution of the time estimates is not known, however the following features for the distribution of the time estimates are valid:-

1. The estimates are limited by two positive end points.
2. The distribution of the time estimates may be symmetric or skewed either to the left or to the right.
3. The shape of the time distribution is not constant but varies according to the time estimate values.
4. The exact distribution may not be a continuous one, but continuous function closely approximate a discrete one.

Because the beta distribution possesses all of the above features, it seems to be reasonable to use it to approximate the uncertainty in the time estimates.

The general beta density function is given by:-

$$F(y) = \frac{\Gamma(K_1 + K_2)}{\Gamma(K_1)\ \Gamma(K_2)} * \frac{1}{(b - a)^{k_1 + k_2 - 1}} * (y - a)^{k_1 - 1} (b - y)^{k_2 - 1}$$

$$K_1, K_2 \geq 0 \qquad a \leq y \leq b$$

$= 0$ Elsewhere

Where:-

a:- The lower limit of the distribution.

b:- The upper limit of the distribution.

K_1, K_2 are the shape parameters.

Converting the general form into the standard form can be achieved by introducing a new variable defined on the (0,1) interval instead of (a,b) interval.

The new variable, say X, is related to the general form variable by the following equation:-

$$X = \frac{y - a}{b - a} \Longrightarrow y = a + (b - a)\ X$$

$$\partial y = (b - a)\ \partial x \quad , \quad f(y) = f(x)\ \frac{\partial x}{\partial y}$$

$$f(x) = \frac{\Gamma(K_1 + K_2)}{\Gamma(K_1)\ \Gamma(K_2)} * \frac{1}{(b - a)^{k_1 + k_2 - 1}} * (b - a)^{k_1 - 1} * X^{k_1 - 1}$$

$$* (b - a)^{K_2 - 1} * (1 - X)^{K_2 - 1} * (b - a)\ \partial x$$

$$f(x) = \frac{\Gamma(K_1 + K_2)}{\Gamma(K_1)\ \Gamma(K_2)} * X^{k_1 - 1}\ (1 - X)^{K_2 - 1}$$

and since the beta function is a density one, the value of:-

$$\int_0^1 f(x)\ dX = 1$$

$$\Longrightarrow \frac{\Gamma(K_1 + K_2)}{\Gamma(K_1)\ \Gamma(K_2)} * \int_0^1 X^{k_1 - 1}\ (1 - X)^{K_2 - 1}\ dx = 1$$

$$\Longrightarrow \frac{\Gamma(K_1 + K_2)}{\Gamma(K_1)\ \Gamma(K_2)} = \frac{1}{\int_0^1 X^{k_1 - 1}\ (1 - X)^{K_2 - 1}\ dx}$$

$$\text{So} \qquad f(x) = \frac{X^{k_1 - 1}\ (1 - X)^{K_2 - 1}}{\int_0^1 X^{k_1 - 1}\ (1 - X)^{K_2 - 1}\ dx}$$

The actual mean for the standard form=

$$\mu = K_1 \ / \ K_1 + K_2 \tag{1}$$

And the actual variance=

$$\delta^2 = \frac{K_1\ K_2}{(K_1 + K_2 + 1)\ (K_1 + K_2)^2}$$

4.2 MODELING A BETA DISTRIBUTION FOR THE TIME ESTIMATES

In this research a beta density function will be modeled for each activity and resource from their three time estimates by equating the actual parameters of the beta distribution to the parameters approximated by PERT.

The PERT approximations for the mean and standard deviation are as follows:-

$$\mu_e = (a + 4m + b)/ 6 \qquad (3)$$

$$\sigma^2 = (b - a)^2/ 6 \qquad (4)$$

By converting the previous parameters into the (0-1) interval they become as follows:

$$\mu_e = \frac{\left(\frac{a + 4m + b}{6}\right) - a}{b - a}$$

$$= \frac{a + 4m + b - 6a}{6(b - a)} = \frac{4m + b - 5a}{6(b - a)} \qquad (3')$$

$$\sigma^2 = \left(\frac{b - a}{36}\right)^2 * \frac{1}{(b - a)^2} = \frac{1}{36} \qquad (4')$$

By equating the actual mean to the PERT mean on the (0-1) interval:-

$$\frac{4m + b - 5a}{6(b - a)} = \frac{K_1}{K_1 + K_2}$$

$$6K_1(b - a) = 4mK_1 + b K_1 - 5aK_1 + 4mK_2 + bK_2 - 5K_2a$$

$$6bK_1 - 6aK_1 - 4mK_1 + 5aK_1 = K_2 (4m + b - 5a)$$

$$K_1(5b - a - 4m) = K_2(4m + b - 5a)$$

$$K_1 = \frac{K_2(4m + b - 5a)}{(- a + 5b - 4m)} = K_2\left[\frac{5a - 4m - b}{a + 4m - 5b}\right]$$

Let $K = \dfrac{5a - 4m - b}{a + 4m - 5b}$

$\Longrightarrow K_1 = K * K_2$

Now by equating the actual variance to the PERT variance on the (0 - 1) interval:-

$$\frac{1}{36} = \frac{K_1 * K_2}{(K_1 + K_2 + 1)\ (K_1 + K_2)^2}$$

Substituting the value of K_1 in terms of K & K_2 in the above equation:-

$$\frac{1}{36} = \frac{K * K_2}{(KK_2 + K_2 + 1)\ (KK_2 + K_2)^2}$$

$$36\ KK_2 = (KK_2 + K_2 + 1) * (K^2K_2^2 + 2KK_2^2 + K_2^2)$$

$$= (KK_2 + K_2 + 1) * K_2^2 * (K_2^2 + 2K + 1)$$

$$36\ KK_2^2 = (KK_2 + K_2 + 1)\ (K_2^2)\ (K + 1)^2$$

$$36\ K = \left[K_2(K + 1) + 1\right]\ (K + 1)^2$$

$$= K_2(K + 1)^3 + (K + 1)^2$$

$$\Longrightarrow \qquad K_2 = \frac{36K - (K + 1)^2}{(K + 1)^3} = \frac{34K - K^2 - 1}{(K + 1)^3}$$

The previous results are summarized as follows:-

$$K = \frac{5a - 4m - b}{a + 4m - 5b}$$

$$K_2 = \frac{34K - K^2 - 1}{(K + 1)^3}$$

$$K_1 = K * K_2$$

$$f(x) = \frac{X^{k_1 - 1}(1 - X)^{K_2 - 1}}{\int_0^1 X^{k_1 - 1}(1 - X)^{K_2 - 1}\ dx}$$

4.3 SIMULATION

There are different definitions of simulation. Jerry Banks defined simulation as "the imitation of the operation of a real-world process or system over time whether done by hand or computer. Simulation involves the generation of an artificial history of a system, and the observation of that artificial history characteristics of real system " [8].

The simulation approach adopted in this research is the Monte Carlo simulation which can be defined as the technique of selecting numbers randomly from one or more probability distributions for use in a particular trail or run in a simulation study. Monte Carlo simulation can be applied where it is impossible or inconvenient to find some other techniques for tackling the problem.

4.3.1 RANDOM NUMBER GENERATORS

A random number generator can be defined as a function or subroutine available in the computer library. It's purpose is to draw (generate) values randomly from a population uniformly distributed between 0.0 and 1.0.

All computers have one or more random number generators in their libraries. The topic of random number generation and testing it's randomness has received more attention by researchers, and a considerable literature is available in this area. It is not the intention of the writer to elaborate on this topic due to it's extensive methodology

4.3.2 GENERATING THE RANDOM VARIABLES

The first step in generating the random variable is to calculate the cumulative probability for each beta density function fitted from the three time estimates. This can be performed by dividing the range of the distribution into a predetermined number of sub-intervals (the number of sub-interval is discussed in the next section).

The area under the beta function between the end points of each sub-interval is computed, and the area under the first sub-interval is added to the next one and so on up to the last sub-interval where the total sum should be equal to one.

The second step is to draw a value on the (0-1) interval by the random number generator from a uniformly distributed population. A process called table-look-up is performed to determine the cumulative probability interval in which the drawn random number falls.

Linear interpolation is performed next between the end points of the sub-interval, and the number resulting from the interpolation is then returned as the time value.

Example 4.1

Given the three time estimates as (2,4,6) and the value of the random number drawn on the (0-1) interval is 0.446. The procedure of finding the corresponding time values is explained below:

The beta density function should first be fitted from the three time estimates:-

$$K = \frac{5a - 4m - b}{a + 4m - 5b} = \frac{5 * 2 - 4 * 4 - 6}{2 + 4 * 4 - 5 * 6} = 1$$

$$K_2 = \frac{34K - K^2 - 1}{(K + 1)^3} = \frac{34 - 1 - 1}{(2)^3} = 4$$

$$K_1 = K * K_2 = 1 * 4 = 4$$

$$F(X) = \frac{X^3 * (1 - X)^3}{\int_0^1 X^3 * (1 - X)^3 * dx}$$

Let number of sub-intervals equal 10, then, the end points of the sub-intervals on the (0-1) interval (the standard variable form) are:-

(0 - 0.1), (0.1 - 0.2), (0.2 - 0.3), ..., (0.9 - 1.0)

Figure (4.1) shows these sub-intervals.

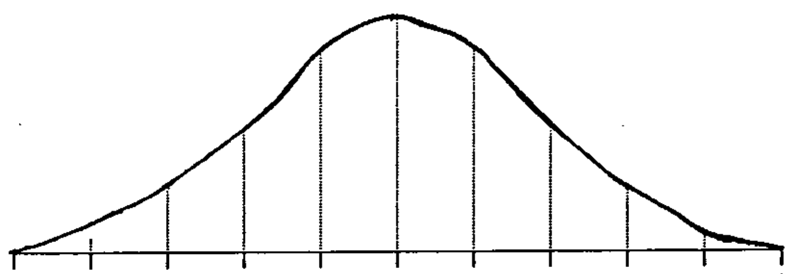


Fig. (4.1)

The area which belongs to any intermediate limit of the sub-interval equals the function value at this limit multiplied by the width of the interval. The areas which belong to the initial and terminal limits are equal to the average value between the value of the function at these limits and the value of the function at the adjacent limits multiplied by half of the width of the sub-interval.

$$F(X) = \frac{X^3 (1 - X)^3}{C} \qquad \text{where } C = \int_0^1 X^3 (1-X)^3 .dx$$

$F(0) = (0)^3 (1-0)^3 / C = 0 = 0$

$F(.1) = (1)^3 (0.9)^3 / C = 0 = .00073/C$

$F(.2) = (.2)^3 (.8)^3 / C = 0 = .00410/C$

$F(.3) = (.3)^3 (.7)^3 / C = 0 = .00926/C$

$F(.4) = (.4)^3 (.6)^3 / C = 0 = .01382/C$

$F(.5) = (.5)^3 (.5)^3 / C = 0 = .015625/C$

$F(.6) = (.6)^3 (.4)^3 / C = 0 = .01382/C$

$F(.7) = (.7)^3 (.3)^3 / C = 0 = .00926/C$

$F(.8) = (.8)^3 (.2)^3 / C = 0 = .00410/C$

$F(.9) = (.9)^3 (.1)^3 / C = 0 = .00073/C$

$F(1) = (1)^3 (0)^3 / C = 0 = 0$

The area belonging to each limit is shown in the following table:-

Table 4.1

*Area * 10^{-4}/C*	1.825	7.3	41	92.6	138.2	156.25	138.2	92.6	41	7.3	1.825
Limit	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1

The cumulative probability corresponding to each limit is shown in table (4.2):-

Table 4.2

Cumulative $* 10^{-4}/C$	1.825	9.125	50.125	147.725	280.925	437.175	575.375	667.975	708.957	716.275	718.1
Limit	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1

$$\text{But} \int_0^1 F(X) = 1 = \frac{10^{-4}}{C} * 718.1 \Longrightarrow C = .07181$$

The final cumulative probability is computed by dividing each value by the C value (.07181) and multiplying by 10^{-4}.

The final results are summarized in table 4.3:-

Table 4.3

C	0.0025	0.0127	0.0698	0.206	0.391	0.609	0.801	0.93	0.987	0.997	1
L	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1

Figure (4.2) shows the cumulative probability

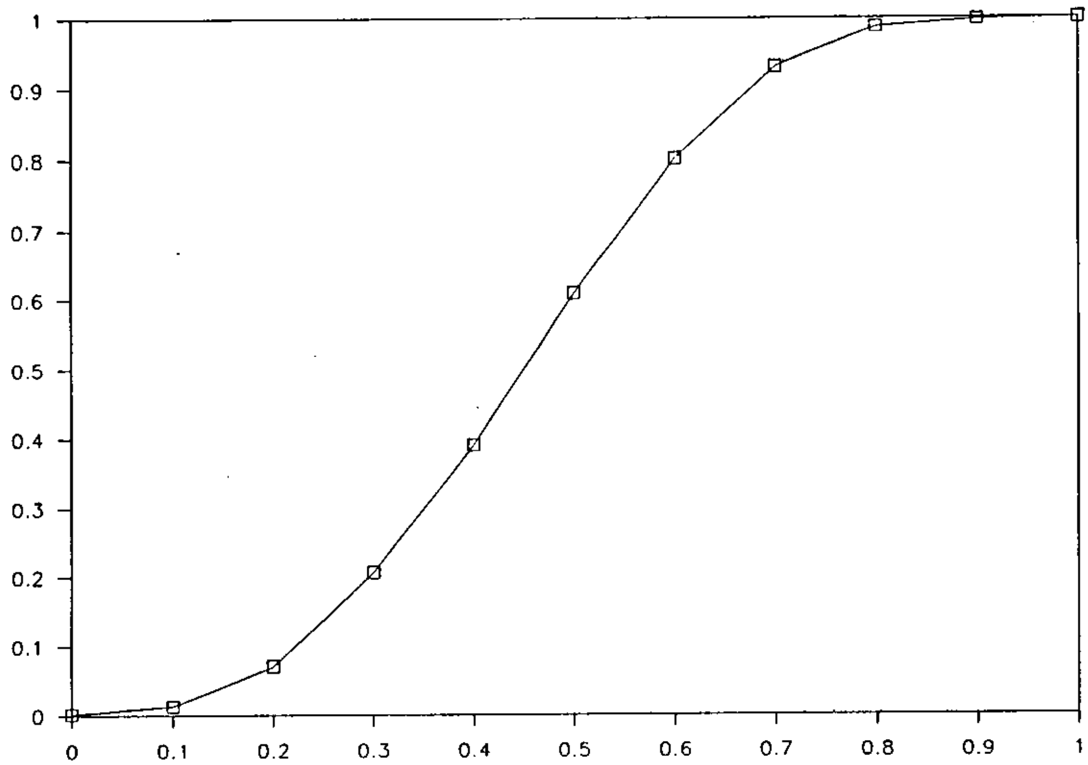
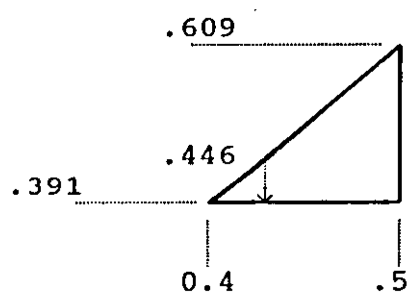


Fig. (4.2)

The random value of (.446) falls in the sub-interval of (.391-.609) corresponding to the time limits of (.4-.5) the exact value can be found by the linear interpolation as follows:-



0.4 + (.446 - .391) * (.5 - .4)/(.609 - .391) = 0.425

The time value on (2-6) interval = 2 + .425 (6-2) = 3.7

4.4 DETERMINING THE APPROPRIATE NUMBER OF SUB-INTERVALS DIVIDING THE RANGE OF BETA FUNCTION

When the random number generator selects a value on the (0-1) interval, the processor starts to look for the sub-interval in which the random value falls in a direction from the extreme left sub-interval to the right. For example, if the first sub-interval is the right one, the processor stops and a linear interpolation is performed. Otherwise the processor continues to check the second, the third, up to the last one.

This process (table-look-up) consumes time, and on the average the number of checking steps equals to the half of the number of the sub-intervals in the case of the symmetric beta distribution, and less than that number if its skewed to left, and more if it is skewed to the right.

Thereby increasing the number of sub-interval increases the processing time, on the other hand, increasing number of sub-interval gives more reliable results.

The suitable number is the one which compromises between the two previous factors. The following analysis is performed to determine a suitable number of the sub-intervals:-

* A sample of nine activities represents most of the activities encountered in practice were simulated on the computer to find their means and standard deviations.

According to the length of their durations the nine activities were divided into the following three groups:-

- *The short activity duration group:-*

  It consists of three activities, the first has a symmetrical beta density function and the other two are either skewed to the left or to the right.

- The second and the third group are of the medium and long duration groups respectively, the beta function of the activities of each group have similar shapes to those in the first group.

Each activity is simulated on the computer programme developed within the research, the number of simulation runs is 100.

Table (4.4) shows the three time estimates for each activity and gives the mean and the standard deviation at 100 simulation runs at different number of sub-intervals.

From the table, the mean and the standard deviation at number of sub-intervals equal to 10 were very close to the actual one, and accurate enough to be used for the scheduling process. At the same time only five checking steps on the average is required. Hence, ten sub-intervals are used for each activity and resource type in this research.

If the actual results are assumed to be equal to the results at number of sub-intervals equal to 100, then the % of

Table (4.4)

a,b,m		Number of Sub-intervals									
		3	4	6	8	10	12	14	20	100	% of error at No. of Sub-Interval= 10
2,4,6	μ	4.023	4.086	4.047	4.046	4.02	4.017	4.012	4.01	3.995	0.63
	σ	1.013	0.855	0.706	0.668	0.65	0.639	0.624	0.622	0.632	2.8
2,3,6	μ	3.431	3.345	3.322	3.318	3.32	3.338	3.338	3.333	3.322	.06
	σ	0.814	0.718	0.706	0.642	0.65	0.636	0.644	0.637	0.628	3.5
2,5,6	μ	4.7	4.86	4.781	4.778	4.725	4.727	4.715	4.7	4.67	1.2
	σ	0.853	0.733	0.705	0.649	0.661	0.633	0.66	0.635	0.632	4.5
5,20,35	μ	19.807	20.159	19.908	20.006	19.855	19.897	19.875	19.913	19.937	.4
	σ	7.585	6.394	5.27	5	4.869	4.786	4.667	4.651	4.739	2.7
5,10,35	μ	14.618	13.64	13.31	13.182	13.076	13.055	13.168	13.148	13.182	.8
	σ	6.017	5.261	5.033	4.865	4.721	4.826	4.84	4.71	4.726	.11
5,38,35	μ	25.618	26.617	27.362	27.697	27.808	27.831	27.81	27.879	28.05	.86
	σ	5.282	4.92	4.848	4.507	4.476	4.766	4.833	4.675	4.73	5.4
10,50,90	μ	49.669	50.403	49.736	50.002	49.602	49.668	49.657	49.761	49.83	0.46
	σ	20.227	17.051	14.052	13.333	12.983	12.761	12.446	12.402	12.638	2.7
10,15,90	μ	34.807	32.006	29.072	28.404	27.923	27.336	27.259	26.962	26.304	6.1
	σ	14.804	13.779	12.747	12.448	12.512	12.64	12.154	12.234	12.484	.22
10,80,90	μ	64.673	67.606	69.071	69.803	69.223	69.935	70.059	70.121	70.08	1.2
	σ	14.861	13.114	13.029	12.226	12.376	12.906	12.83	12.846	12.64	2.1

error in the mean and the standard deviation obtained at number of sub-intervals equals 10 can be calculated as follows:-

$$\text{\% of error in the mean} = \frac{\mu_{10} - \mu_{100}}{\mu_{100}} * 100\%$$

$$\text{\% of error in the standard deviation} = \frac{\sigma_{10} - \sigma_{100}}{\sigma_{100}} * 100\%$$

4.5 UNCERTAINTY OF RESOURCE AVAILABILITY:-

In this research the uncertainty associated with resource availability is considered. Uncertainty of resource availability means that the exact date on which the resource is available for a new project is probabilistic. Uncertainty in the delivery time of the construction equipment, in releasing the resources from the ongoing project, and of joining new employees are the main factors which cause the uncertainty.

The availability of uncertain resources is expressed in terms of the PERT three estimates (pessimistic, most likely, optimistic). These time estimates are based on the time when the resources are expected to become available with reference to the start date of the new project.

The beta density function can be formulated from the three time estimates by equating the actual mean and standard deviation to the approximate PERT parameters. Also, the cumulative probability computation, the generation of random numbers, and the table-look-up process are performed by a procedure similar to the one of the activity duration time.

4.5.1 THE ALTERNATIVES WHICH CAN BE GENERATED OF THE UNCERTAIN RESOURCES

The resources can be divided into two types according to the certainty of their availability: certain resources like the hired resources, and uncertain resources due to the factors mentioned above. The choice of using either certain or uncertain resource is not an easy task. The uncertain resources, are usually cheaper since they are considered, most of the time, as in-house resources, but due to their uncertainty, the completion time of the project may be increased. On the other hand, certain resources are expensive but decrease the completion time of the project.

The software developed within this research helps the managers in their decision-making process in choosing a suitable alternative among the alternatives available. The software performs a comprehensive analysis about each available alternative. It computes project completion time, the cost, and the performance probability associated with different alternatives.

The following three cost coefficients have been considered in this research:

1) Cost of hired resources per unit of time.
2) Over head cost per unit time.
3) Penalty cost per unit time.

Three different types of resources are used and considered to be either certain or uncertain.

The cost formula used in calculating the cost associated with each alternative is:

$$C = \sum_{i=1}^{3} Ch_i t_i + C_0 * (T_c - T_s) + C_P * (T_c - T_{sch}).$$

Where ch_i = is the hiring cost of resource type i per unit of time.

t_i = The hiring time units of resource type i.

C_0 = Over head cost per time unit.

T_c = The completion date of the project.

T_s = The starting date of the project.

C_p = Penalty cost per time unit.

T_{sch} = The scheduled completion time.

If the availability of the three resources are uncertain, the following twelve alternatives are formulated by the software.

- The actual problem
- Replacing each type of resource by certain resource. The replacement is performed by replacing only one type at a time (three alternatives can be generated by this step).
- Only two types of uncertain resources are replaced by certain resources (three alternatives are produced).
- Replacing the three uncertain resources by other three certain resources.
- The remaining four alternatives are formulated by shifting

the starting date of the project by a certain time. Shifting (delaying) the starting time will increase the the project completion time but increases the performance probability and decrease the over head cost.

The following four delaying periods for the starting date generate the four alternatives:-

1) Shifting by a period = B_{max}.
2) Shifting by a period $=3B_{max}/ 4$
3) Shifting by a period $=2B_{max}/ 4$
4) Shifting by a period = $B_{max}/ 4$

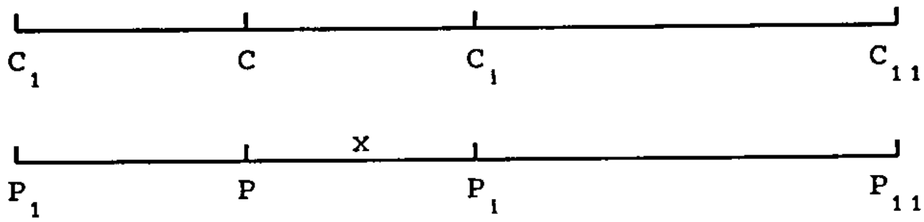
Where B_{max} = the maximum pessimistic time of the three resources.

The computation of the cumulative probability and the end point of the sub-intervals should be modified at any shifting in the starting date. This modification can be achieved by the following procedure:-

Let P_1, P_2,......,P_{11} the limits of the sub-intervals, and C_1, C_2, ...,C_{11} the corresponding cumulative probabilities And P equal to the shifting value of the starting date. The value of the cumulative probability corresponding to P = C.

$$\text{The modified limit } \bar{P_i} = \max (P_i - P,\ 0.0)$$

The modified cumulative probabilities corresponding to the points less than or equal to the shifted value equal zero. For other points, the modified cumulative probability at point p_i can be found by applying the following conditional probability law:



$$C_i^- = P\,(x \le P_i / x \ge P)$$

$$= \frac{P\,(x \le P_i) \cap (x \ge P)}{P\,(x \ge P)}$$

$$= \frac{C_i - C}{1 - C}$$

Example 4.2:

Let (a,m,b) = (2,4,6) the three time estimates of the uncertain resource. The cumulative probability and the end points of the sub-intervals are computed in example 4.1 and summarized in table (4.5).

Table 4.5

C	0.003	0.01	0.07	0.199	0.391	0.609	0.801	0.93	0.987	0.997	1
P	2	2.4	2.8	3.2	3.6	4	4.4	4.8	5.2	5.6	6

Let the shifting in the starting date equal to 3 units.

The modified end points=

P_1^- modified = max (2-3,0) = 0

P_2^- modified = max (2,4-3,0) = 0

P_3^- modified = max (2,8-3,0) = 0

P^-_4 modified = max (3,2-3,0) = 0,2

P^-_5 modified = max (2,6-3.0) = 0,6

P^-_6 modified = max (4-3,0) = 1.00

P^-_7 modified = max (4,4-3) = 1.4

P^-_8 modified = max (4,8-3) = 1.8

P^-_9 modified = max (5,2-3) = 2.2

P^-_{10} modified = max (5,6-3) = 2.6

P^-_{11} modified = max (6-3) = 3

The cumulative probability at the value of the shift can be found by linear interpolation of the original cumulative probability table as follows:-

$$C = .07 + \left(\frac{.199 - .07}{3.2 - 2.8}\right) * (3 - 2.8) = .1345$$

$$C^-_1 = 0$$

$$C^-_2 = 0$$

$$C^-_3 = 0$$

$$C^-_4 = \frac{.199 - .1345}{1 - .1345} = .0745$$

$$C^-_5 = \frac{.391 - .1345}{1 - .1345} = .2960$$

$$C^-_6 = \frac{.609 - .1345}{1 - .1345} = 0.548$$

$$C^-_7 = \frac{.801 - .1345}{1 - .1345} = 0.770$$

$$C^-_8 = \frac{.930 - .1345}{1 - .1345} = 0.919$$

$$C^-_9 = \frac{.897 - .1345}{1 - .1345} = 0.985$$

$$C^-_{10} = \frac{.997 - .1345}{1 - .1345} = 0.996$$

$$C^-_{11} = \frac{1.00 - .1345}{1 - .1345} = 1.00$$

The modified end points of the sub-intervals and the corresponding cumulative probabilities are shown in table 4.6.

Table 4.6

C^{-}	0	0	0	0.0745	0.2960	0.548	0.770	0.919	0.985	0.996	1.00
P^{-}	0	0	0	0.2	0.6	1.0	1.4	1.8	2.2	2.6	3

4.6 THE HEURISTIC RULE ADOPTED IN THIS RESEARCH

The heuristic rule determines the priorities to the conflicting activities in the scheduling process according to one or more parameters associated with these activities. The solution obtained by the heuristic rules may not be an optimal one but most of the time is close to the optimal.

EDWARD .W [7] had performed a research on the performance of ten different heuristic rules, the solutions obtained by these rules was compared to the solution obtained by the optimal techniques. The research revealed that none of the ten heuristics performed consistently best on all problems, but the minimum float rule exhibited a very close results to the optimal one and the late finish rule also exhibited a close results to those of the minimum float rule.

The late finish rule criterion was adopted in this research due to its efficiency which is proved through different research and since the minimum float required updated of the float of the activities continuously which consumes more processing time.

4.7 THE SAMPLE SIZE

The sample size is defined as the number of simulation runs, on each run a complete project scheduling is performed, and the calculated results are added to the results of the next run and so on, up to the last run. Then the mean and the standard deviation are calculated.

The accuracy of these results depends on the sample size, the larger the sample size the more accurate results are obtained. The suitable sample size which may produce reliable results is function of the following two factors:

1. The range (standard deviation) of the random variables existing in the problem, the greater the standard variables of the problem, the greater the sample size required.
2. Other factors related to the structure of the problem such as the number of the random variables and inter-dependency among these random variables.

Usually the variances of the random variables in the project scheduling problem are small which may require small sample size.

In order to determine the appropriate sample size of this problem, the following experiment is conducted:-

Ten different problems were chosen randomly from different books and simulated at different sample size [10, 25, 50, 100, 150, 200, 300, 500, 1000]. The obtained mean and standard deviation are tabulated in table (4.7). The table shows that there is a noticeable difference in the mean and the standard deviation of sample sizes 10, 25, 50, when they are compared to the results of sample size 1000. Also, it shows that the results of sample sizes 100 & 1000 are very close to each other.

If the results of sample size 1000 are considered as the actual one, then the error in the mean and the standard deviation associated with the 100 sample size can be calculated by the following formula:-

$$\%\ \text{error of the mean} = \frac{\mu_{100} - \mu_{1000}}{\mu_{1000}} * 100\%$$

$$\%\ \text{error at the standard deviation} = \frac{\sigma_{100} - \sigma_{1000}}{\sigma_{1000}} * 100\%$$

The calculated errors are tabulated at the same table (4.7). These errors are negligible especially the errors associated with the mean, so the sample size of 100 can be adopted for this research.

The ten different problems are listed in appendix 1.

Table (4.7)

EXAMPLE	The Sample Size (No. Of Simulation Run)										% of error at sample size of 100
		10	25	50	100	150	200	300	500	1000	
EX1	μ	12.93	12.89	12.95	13	12.97	12.98	13.06	13.08	13.05	0.38
	σ	0.25	0.2	0.23	0.29	0.3	0.3	0.31	0.33	0.33	12.12
EX2	μ	32	31.94	32.02	32.11	32.14	32.16	32.24	32.26	32.31	0.62
	σ	0.94	0.74	0.86	0.76	0.8	0.85	0.8	0.91	0.91	16.5
EX3	μ	48.72	48.9	49.35	49.42	49.49	49.54	49.62	49.66	49.67	0.5
	σ	0.66	0.5	0.64	0.89	0.81	0.83	0.73	0.73	0.75	18.67
EX4	μ	49.9	49.76	49.88	50.11	50.31	50.29	50.26	50.23	50.26	0.3
	σ	1.91	2.05	1.56	1.42	1.57	1.76	1.72	1.72	1.81	20.1
EX5	μ	52.06	52.16	52.93	53.23	53.01	53.09	53.22	53.15	53.12	0.21
	σ	1.92	1.15	2.48	2.69	2.51	2.42	2.58	2.4	2.55	5.5
EX6	μ	60.3	59.96	60.88	61.39	61.69	61.86	61.96	61.87	61.71	0.52
	σ	4.33	5.28	6.62	6.5	8.27	8.16	8.95	8.7	8.26	21.3
EX7	μ	78.59	78.52	80.25	80.5	80.66	80.71	80.82	80.9	80.74	0.3
	σ	2.8	4.27	7.84	7.19	7.52	7.25	7.18	7.64	7.79	7.7
EX8	μ	80.95	80.6	81.16	81.52	81.68	81.65	81.67	81.49	81.55	0.04
	σ	3.69	3.98	4.82	4.3	4.47	4.52	4.83	4.75	5.09	12.2
EX9	μ	101.07	101.8	102.82	103.45	103.8	103.72	103.81	103.93	103.87	0.07
	σ	5.3	7.61	7.22	9.12	10.52	10.26	10.75	10.49	10.44	0.77
EX10	μ	133.33	133.66	134.74	135.11	135.51	135.59	135.62	135.88	135.88	0.27
	σ	5.3	7.61	7.22	9.12	10.52	10.26	10.75	10.46	10.44	1.7

4.8 COMPUTER LANGUAGE: BASIC

BASIC, which stands for Beginner's All-purpose Symbolic Instruction Code, was developed at Dartmouth college in 1964 as a teaching language.

BASIC is the most popular computer language in the world . A recent survey by Boston computer society revealed that more than 80% of its programmer members use BASIC and about 500,000 high school and college students enroll in BASIC courses every year [9].

One of the complied BASIC languages is the Quick Basic, which is easy to learn and to use. A compiler is available within the Quick Basic as a sub-program, its function is to read and understand the instructions of a BASIC program and then to check them for certain type of errors, after that it translates them into machine language which enables the processor to execute these instructions directly and quickly to accomplish the tasks of the Basic program.

4.8.1 THE STRUCTURE AND DESIGN OF THE DEVELOPED SOFTWARE

The use of computers for scientific and engineering purposes receives an overwhelming appreciation from people devoted to such fields of interests.

Advances in micro electronics made it possible to produce machines of such memory capacity and speed that under many conditions of use memory size places no limitations, on the programmer [9].

A software was developed in Quick Basic language to achieve the thesis objective, this software is menu driven, and user-friendly program.

The software performs the following tasks:-

1. Generates the Beta density function from the three time estimates for both the activities and the resources.
2. Calculates the cumulative probabilities.
3. Performs the CPM computations to be used in the priority criterion for the resource allocation.
4. Starts simulation and performs the resource allocation scheduling for each run.
5. Performs the statistical and cost calculations, and then tabulates the results on the screen or prints them as a hardcopy.
6. If the user objective is to generate the different alternatives, steps 4 & 5 are repeated twelve times.

The best way of describing the software is done through its menus in the next section.

4.8.2 THE MAIN MENUS OF THE SOFTWARE

A short description of the software is displayed on the screen after the execution, then the following menus are followed:-

1. The first menu is shown below

```
CHOOSE ONE OF THE FOLLOWING:-
1- SOLVE STOCHASTIC RESOURCES & ACTIVITIES SCHEDULING
   PROJECT.
2- CHOOSE THE BEST AVAILABLE ALTERNATIVE.
3- EXIT TO SYSTEM.
```

It gives the choice to select between solving a scheduling project problem, or finding the best alternative.

2. After the user selects any of the above first two selections, the second menu is shown as follows:-

```
CHOOSE ONE OF THE FOLLOWING:-
1- ENTER NEW PROBLEM.
2- READ AN EXISTING PROBLEM.
```

This menu gives the user to select either solving a new problem or solving an already existing problem on a file. If the second choice is selected the processor asks the user to enter the name of the existing file of the problem, and if the user wants to solve a new problem the following questions are displayed:-

```
ENTER PROJECT NAME?
ENTER SUPERVISOR NAME?
ENTER NUMBER OF ACTIVITIES?
```

Then for each type of resource the following questions are displayed:-

```
ENTER NUMBER OF RESOURCES AVAILABLE?
ENTER THE OPTIMISTIC AVAILABILITY TIME?
ENTER THE MOST LIKELY AVAILABILITY TIME?
ENTER THE PESSIMISTIC AVAILABILYTY TIME?
```

Next for each activity the following questions are also displayed:

```
NUMBER OF STARTING NODE = ?
NUMBER OF THE ENDING NODE = ?
THE OPTIMESTIC ACTIVITY TIME  = ?
THE MOST LIKELY ACTIVITY TIME = ?
THE PESSIMISTIC ACTIVITY TIME = ?
RESUORCE REQUIREMENT OF TYPE 1 = ?
RESUORCE REQUIREMENT OF TYPE 2 = ?
RESUORCE REQUIREMENT OF TYPE 3 = ?
```

Then the processor performs preliminary checks for the three time estimates of the activities and the resources, being one of them is inconsistent, the processor gives an error sign and the user can correct the wrong entries. The same thing is performed for the starting and the ending node numbers.

3. The third menu asks the user to enter the number of simulation runs.
4. In the forth menu all the input data are displayed on the screen and gives the opportunity for the user to detect the wrong data, and to correct them if any.
5. The input data for the resources are also displayed, so the user may correct the wrong data if any.
6. After the input data are confirmed the sixth menu is displayed as below:-

```
CHOOSE ONE OF THE FOLLOWING:
1- SAVE THE PROBLEM
2- SOLVE THE PROBLEM
3- RETURN TO MAIN MENU
```

If the first choice is chosen, a file name must be entered, so that the data can be saved, then the processor return the sixth menu.

If selection number two was chosen, the processor starts solving the problem and the current number of simulation is seen on the screen.

7. After solving the problem the last menu displayed on the screen as follows:-.

```
CHOOSE ONE OF THE FOLLOWING:
1- DISPLAY SOLUTION ON SCREEN.
2- PRINT SOLUTION.
3- SOLVE PROBLEM.
4- RETURN TO PREVIOUS MENU.
5- RETURN TO MAIN MENU.
```

By choice number one the results a redisplayed on the screen in tableau format, and if a hard copy of the results is required then selection number two should be specified.

After the execution any of the first two selections the same menu reappears, and when the user wants to quit from the program he should return to the main menu by specifying selection number five, and within the main menu, choice number three should be specified.

Figure (4.3) shows the flowchart of the software.

4.8.3 VALIDATION OF THE SOFTWARE

The software consists of various subroutines, each of

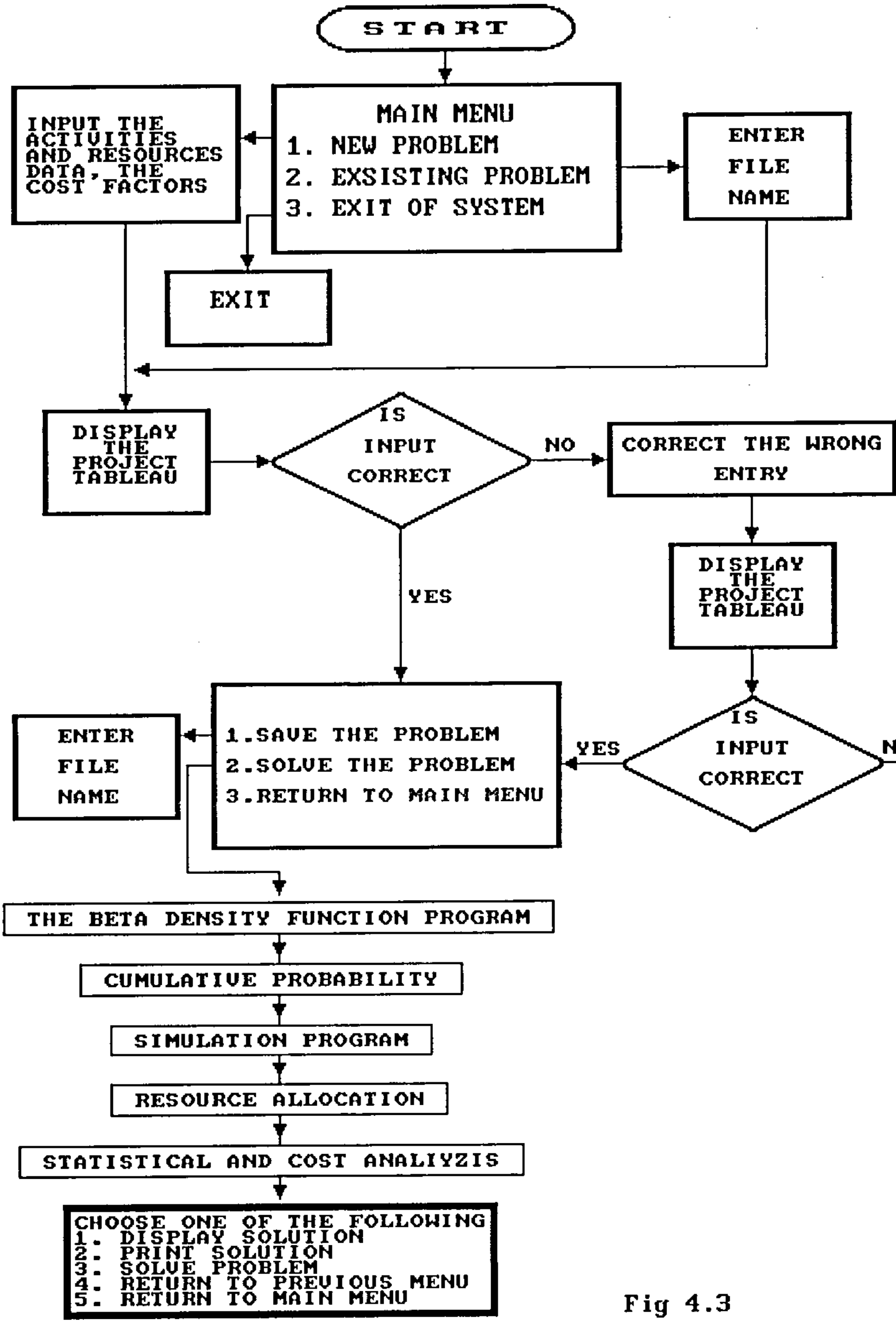

START
MAIN MENU
1. NEW PROBLEM
2. EXSISTING PROBLEM
3. EXIT OF SYSTEM
INPUT THE ACTIVITIES AND RESOURCES DATA, THE COST FACTORS
ENTER FILE NAME
EXIT
DISPLAY THE PROJECT TABLEAU
IS INPUT CORRECT
NO
CORRECT THE WRONG ENTRY
DISPLAY THE PROJECT TABLEAU
YES
IS INPUT CORRECT
NO
YES
ENTER FILE NAME
1.SAVE THE PROBLEM
2.SOLVE THE PROBLEM
3.RETURN TO MAIN MENU
THE BETA DENSITY FUNCTION PROGRAM
CUMULATIVE PROBABILITY
SIMULATION PROGRAM
RESOURCE ALLOCATION
STATISTICAL AND COST ANALIYZIS
CHOOSE ONE OF THE FOLLOWING
1. DISPLAY SOLUTION
2. PRINT SOLUTION
3. SOLVE PROBLEM
4. RETURN TO PREVIOUS MENU
5. RETURN TO MAIN MENU

Fig 4.3

these subroutines was validated separately by solving different problems both manually and by running the program on the computer. The obtained results were compared to each other, if any difference between the two results is found, the chosen subroutine should be inspected by executing the different part of the program separately to locate the error part(s). And within these parts, the error statements may be located by running each statement separately.

This validation process was facilitated by adding the stop statement at the end of any part requiring inspection.

Also many solved examples existing in project management books were solved within the software after adding certain modification in the input data software. The output results were similar to the results solved in these books.

A hardcopy of the software is listed in appendix 2.

4.9 APPLICATION

The interpretation of the output of the software is discussed in this section. The input for 22-Activity-Project is tabulated in table (4.8), this table shows the starting and the ending node numbers, the three time estimates, and the resources requirements of each activity.

Table 4.8

ACTIVITY NO.	START. NODE	END. NODE	OPTI. TIME	LIKELY TIME	PISSI. TIME	RESOURCES REQUIRMENT		
						TYPE1	TYPE2	TYPE3
1	1	2	5	6	10	2	2	2
2	1	3	4	8	10	1	2	0
3	2	5	4	9	10	3	2	0
4	2	8	15	17	19	2	2	2
5	3	4	2	4	6	2	1	1
6	3	5	4	9	10	2	1	2
7	4	5	4	9	10	2	1	2
8	4	6	15	17	28	2	3	1
9	4	7	9	11	14	2	2	1
10	5	6	2	4	6	2	1	2
11	5	8	2	3	6	2	2	2
12	6	9	2	4	6	2	1	1
13	6	12	1	2	4	1	2	2
14	7	13	2	3	5	2	2	2
15	8	9	4	5	6	1	2	1
16	8	10	2	3	6	1	1	1
17	8	11	3	4	5	2	2	1
18	9	11	2	4	8	1	0	0
19	10	13	2	5	6	1	2	2
20	11	14	5	6	8	1	2	2
21	12	13	4	7	8	1	2	2
22	13	14	5	7	9	1	1	1

The quantity available of each resource and its three time estimates are shown in table (4.9)

Table 4.9

RESOURCE TYPE	NOS.	OPTI.TIME	MOST LIKELY	PESST.TIME
1	3	10	15	20
2	3	6	10	12
3	3	6	13	17

The followings are the cost coefficients of this project:-

THE HIRING COST OF RESOURCE TYPE 1 = 4
THE HIRING COST OF RESOURCE TYPE 2 = 4
THE HIRING COST OF RESOURCE TYPE 3 = 12
THE OVER HEAD COST PER UNIT TIME = 4.5
THE PENALTY COST PER UNIT TIME = 20
THE SCHEDULED DATE = 120

In order to get a complete analysis of the project, the software should execute twice. In the first execution the best available alternative may be specified. The results obtained from this execution are shown in table (4.10).

Table 4.10

ALTERNATIVES AVAILABLE	MEAN	STANDARD DEVIATION	COST AT PERFORMANCE PROB 50%	75%	95%
THE ACTUAL CASE	143.31	9.31	1045.02	1176.20	1420.32
R1 HIRED	138.76	8.42	1015.75	1134.40	1355.19
R2 HIRED	143.81	9.81	1096.96	1235.10	1492.15
R3 HIRED	144.46	9.45	1225.16	1358.22	1605.48
R1 & R2 HIRED	133.60	9.36	972.44	1104.32	1349.72
R1 & R3 HIRED	138.68	7.59	1160.72	1267.59	1466.46
R2 & R3 HIRED	143.94	7.64	1244.35	1351.98	1552.28
R1,R1&R2 HIRED	129.47	6.21	1017.83	1105.29	1268.05
SHIFT BY B/4	143.93	9.36	1058.75	1190.64	1436.06
SHIFT BY 2B/4	144.23	8.16	1066.84	1181.83	1395.83
SHIFT BY 3B/4	144.89	6.25	1077.57	1165.56	1329.29
SHIFT BY B	149.07	7.74	1162.09	1271.11	1473.98
WHERE B = 20 UNITS OF TIME					

The sample size (number of simulation runs) for the previous solution was 100. The output gives the mean of the completion time of the project and its standard deviation for each alternative, also it gives the project cost at different performance probabilities. For example, the cost at 50% performance probability means that the probability of finishing the project by a cost not more than the associated cost is 50% similarly the cost at 95% performance probability means that the probability of finishing the project by a cost not more than the associated cost is 95%.

It is the manager's job to decide the value of the performance probability of the completion time of the project at which he will make his planning and scheduling. The manager differentiates among the alternatives according to their cost at the predetermined performance probability.

The minimum cost and its associated completion time at the specified performance probability may be used for bidding purposes. A manager with gambler's instinct may select the most economical alternative at the lowest performance probability (50%). On the other hand if he prefers not to work through risk he will differentiate among the alternatives at the highest performance probability (95%).

After the best alternative is determined, the software may execute another time to provide the analyst with a complete project scheduling, and with the cost and statistical analysis of the project for the predetermined alternative. In this case, increasing number of simulation runs is justified, since only one alternative is going to be solved.

For this example, comparison among the alternatives is made according to the 50% performance probability. Referring to table (4.10), the minimum cost at this value is the cost associated with alternative number five. This alternative requires to replace the in-house (uncertain) resources of type 1 & 2 by hired resources (certain resources).

Table (4.11) shows the early start and finish of each activity after executing the software for alternative number five at 1000 simulation runs.

Table 4.11

ACTIVITY NUMBER	I	J	ES	EF
1	1.00	2.00	12.44	18.88
2	1.00	3.00	0.00	7.74
3	2.00	5.00	66.09	74.42
4	2.00	8.00	41.38	58.38
5	3.00	4.00	18.88	22.87
6	3.00	5.00	64.78	73.14
7	4.00	5.00	67.62	75.94
8	4.00	6.00	22.87	41.38
9	4.00	7.00	83.40	94.54
10	5.00	6.00	94.54	98.53
11	5.00	8.00	98.53	101.86
12	6.00	9.00	105.16	109.16
13	6.00	12.00	101.86	104.01
14	7.00	13.00	120.64	123.80
15	8.00	9.00	104.01	109.00
16	8.00	10.00	101.86	105.16
17	8.00	11.00	123.25	127.24
18	9.00	11.00	111.52	115.86
19	10.00	13.00	115.68	120.38
20	11.00	14.00	125.21	131.20
21	12.00	13.00	109.00	115.68
22	13.00	14.00	123.80	130.80

Statistical and cost analysis of the project for the same alternative are shown below.

STATISTICAL ANALYSIS OF THE COMPLETION TIME OF THE PROJECT
NUMBER OF SIMULATION RUNS = 1000.00 THE MEAN OF THE COMPLETION TIME = 133.66 THE STANDARD DEVIATION TIME OF THE PROJECT = 8.21 THE 95% CONFIDENCE INTERVAL FOR THE COMPLETION TIME: (117.5727, 149.7543) THE RANGE FOR THE COMPLETION TIME: (122, 144.7)

COST ANALYSIS
1- THE PROJECT COST AT 50% PERFORMANCE PROBABILITY= 973.6682
2- THE PROJECT COST AT 75% PERFORMANCE PROBABILITY= 1089.321
3- THE PROJECT COST AT 95% PERFORMANCE PROBABILITY= 1304.535

CHAPTER FIVE

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

CHAPTER FIVE

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

5.1 DISCUSSION

In this research stochastic nature of activity duration time and resource availability have been incorporated in the project scheduling process. This incorporation, applicable to most of real life project, enables the analyst to obtain a reliable scheduling.

Fitting the three estimates of both the activity duration and resource availability into a Beta density functions gives more accurate results than using PERT parameters. The Beta function was chosen to approximate the three estimates due to its features which fit the features of these estimates.

Monte Carlo simulation is used in tackling this problem instead of PERT approach which may produce some types of error. These errors are due to PERT assumptions in solving the problem which are revealed through the literature. Also, using the mathematical approaches for this problem may be impractical.

The software provides the analyst with valuable information about cost and statistical analysis. The information enables the manager to minimize the cost of the project by selecting a suitable alternative produced by the software.

In the case of using the software to minimize the cost of the project, and when the number of simulation runs is small, the differentiation among the alternatives may not be accurate, since the differences between the cost of the projects associated with alternatives may be due to the differences in the random numbers used for each alternative. This problem can be solved either by increasing number of simulation runs or by incorporating a random number generator in the software enabling the analyst to use the same random numbers for each alternative.

5.2 CONCLUSIONS

The software developed can be used in different situations. It can be used to solve a CPM-scheduling-project, to solve scheduling project of deterministic resource availability associated with certain or uncertain duration time, and to solve uncertain resource availability associated with certain or uncertain duration time.

This software can be used for different applications. It is used to minimize the cost of the project, in bidding purposes, and gives a complete scheduling.

The number of sub-intervals which divides the range of the Beta function is fixed to ten. It was found that the obtained results using this number are accurate enough to be approved for the project scheduling purposes. At the same time, the processor consumes reasonable amount of time.

The sample size (number of simulation runs) can't be generalized for all project networks, but the percentage of errors of the mean and the standard deviation of the completion time of the project is found to be acceptable at 100 simulation runs. The number of simulation runs is adjustable and the analyst has the freedom of selecting any number.

5.3 RECOMMENDATIONS

The following further researches are recommended:-

1. To overcome the limitations in the software the following modifications are suggested:-

   A- The software tackles only three different types of resources. It is recommended to further increase the number of resource types

   B- Incorporating a graphics programme in this software. By this facility a graph of cost against performance probability can be drawn for each alternative.

   C- Incorporating a random number generator in the software which enables the analyst to use the same values and sequence of random numbers for each alternative. In this case, the obtained results are reliable, and there will be no doubt in the accuracy of the differentiation process among the alternatives.

2. The effectiveness of all the heuristic rules of resource allocation existing in literature were investigated on deterministic project networks. As a further research, it is recommended to investigate these rules on stochastic project networks using the software developed within this research.
3. A research was performed recently by Ihab A. Haddadin tackling the problem of behavior of heuristics rules on the parameters and structure of deterministic project networks. It is recommended to study this behavior on stochastic project networks, by incorporating the two researches.

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EXAMPLE 1

ACTIVITY NO.	START. NODE	END. NODE	OPTI. TIME	LIKELY TIME	PISSI. TIME	RESOURCES REQUIRMENT TYPE 1	TYPE 2	TYPE 3
1	1	2	1	2	4	3	0	0
2	1	4	5	6	7	5	0	0
3	1	3	2	4	5	4	0	0
4	2	4	1	3	4	2	0	0
5	3	4	4	5	7	4	0	0
6	2	5	3	4	5	2	0	0
7	4	5	1	2	3	6	0	0

RESOURCE TYPE	NOS.	OPTI. TIME	MOST LIKELY	PESSI. TIME
1	10	0	0	0
2	0	0	0	0
3	0	0	0	0

EXAMPLE 2

ACTIVITY NO.	START. NODE	END. NODE	OPTI. TIME	LIKELY TIME	PISSI. TIME	RESOURCES REQUIRMENT TYPE 1	TYPE 2	TYPE 3
1	1	2	3	4	5	2	0	2
2	2	3	4	5	6	1	2	2
3	3	4	2	2	2	1	1	1
4	4	11	2	3	4	1	2	2
5	1	5	2	3	4	1	2	2
6	5	6	5	6	7	1	1	1
7	6	7	2	3	4	1	2	3
8	7	11	2	7	8	2	2	2
9	1	8	4	5	6	2	2	2
10	8	11	2	3	4	1	2	1

RESOURCE TYPE	NOS.	OPTI. TIME	MOST LIKELY	PESSI. TIME
1	3	0	0	0
2	3	0	0	0
3	3	0	0	0

EXAMPLE 3

ACTIVITY NO.	START. NODE	END. NODE	OPTI. TIME	LIKELY TIME	PISSI. TIME	RESOURCES REQUIRMENT TYPE 1	TYPE 2	TYPE 3
1	1	2	4	5	6	2	3	2
2	2	3	1	2	3	3	2	2
3	3	4	2	4	5	3	3	3
4	3	16	3	3	3	2	2	2
5	1	5	4	5	6	3	2	3
6	1	7	3	3	3	2	3	1
7	2	5	3	4	6	1	1	1
8	4	10	2	3	4	2	2	2
9	5	6	2	3	4	1	2	3
10	5	8	3	4	5	2	2	2

RESOURCE TYPE	NOS.	OPTI. TIME	MOST LIKELY	PESSI. TIME
1	4	3	4	5
2	3	2	3	4
3	3	1	2	3

ACTIVITY NO.	START. NODE	END. NODE	OPTI. TIME	LIKELY TIME	PISSI. TIME	RESOURCES REQUIRMENT TYPE 1	TYPE 2	TYPE 3
1	1	2	6	7	10	2	2	2
2	2	3	4	6	10	2	3	2
3	3	4	13	18	20	2	1	1
4	4	11	4	6	7	1	2	3
5	1	5	4	5	6	1	1	1
6	5	6	3	3	3	2	2	2
7	6	7	1	1	1	1	1	1
8	7	11	1	2	3	2	2	2
9	1	8	4	6	7	1	1	1
10	8	9	4	5	6	1	1	1
11	9	10	1	2	3	2	2	2
12	10	11	2	3	4	1	1	1

RESOURCE TYPE	NOS.	OPTI. TIME	MOST LIKELY	PESSI. TIME
1	3	4	5	6
2	3	1	2	2
3	3	1	2	2

EXAMPLE 5

ACTIVITY NO.	START. NODE	END. NODE	OPTI. TIME	LIKELY TIME	PISSI. TIME	RESOURCES REQUIRMENT TYPE 1	TYPE 2	TYPE 3
1	2	3	2	3	4	2	2	2
2	1	2	1	2	3	2	2	2
3	2	5	4	5	6	3	3	3
4	3	8	3	6	9	2	1	1
5	3	4	1	2	3	1	1	1
6	1	5	3	4	5	1	2	3
7	1	7	5	5	5	2	2	2
8	5	8	2	2	2	1	1	1
9	5	6	4	4	4	1	2	3
10	6	7	1	2	9	3	3	3
11	7	9	3	6	8	3	2	2
12	2	10	2	3	4	3	2	2
13	9	10	1	2	3	2	2	2
14	9	11	2	6	7	1	1	1
15	10	11	2	6	7	2	1	1

RESOURCE TYPE	NOS.	OPTI. TIME	MOST LIKELY	PESSI. TIME
1	3	1	2	3
2	3	2	2	2
3	3	4	5	5

EXAMPLE 6


```
ACTIVITY START.   END.   OPTI.    LIKELY    0 ;TAB(61);RESOURCES
  NO.    NODE     NODE   TIME      TIME     TIME            REQUIREMENT
                                                   TYPE 1   0  2 ;TAB(71); 0
3
--------------------------------------------------------------------------------
--------
```

11	5	7	2	3	4	4	5	6
12	6	8	2	4	9	5	6	3
13	7	9	1	4	7	4	5	2
14	7	10	2	5	5	6	2	1
15	8	10	3	7	11	1	1	1
16	9	11	0	0	0	0	0	0
17	9	12	1	2	6	3	5	4
18	10	11	1	3	5	3	2	4
19	11	12	1	4	4	4	5	1

RESOURCE TYPE	NOS.	OPTI. TIME	MOST LIKELY	PESSI. TIME
1	6	0	0	0
2	6	2	3	4
3	6	2	3	8

IS THE INPUT RESOURCES CORRECT ? (Y,N)
?

EXAMPLE 7

ACTIVITY NO.	START. NODE	END. NODE	OPTI. TIME	LIKELY TIME	PISSI. TIME	RESOURCES REQUIRMENT TYPE 1	TYPE 2	TYPE 3
1	1	2	2	3	5	2	0	0
2	1	3	2	4	6	3	2	1
3	1	4	2	5	14	3	4	4
4	2	5	4	8	12	2	2	2
5	3	5	8	10	15	2	3	4
6	3	6	3	3	6	2	3	4
7	4	6	6	9	12	3	4	1
8	5	7	2	7	9	2	3	4
9	5	8	1	3	7	3	4	5
10	6	8	2	6	10	2	2	2

RESOURCE TYPE	NOS.	OPTI. TIME	MOST LIKELY	PESSI. TIME
1	4	5	6	7
2	5	0	0	0
3	4	1	3	6

ACTIVITY NO.	START. NODE	END. NODE	OPTI. TIME	LIKELY TIME	PISSI. TIME	RESOURCES REQUIRMENT TYPE 1	TYPE 2	TYPE 3
1	1	2	5	7	10	2	2	2
2	2	3	4	6	20	2	2	2
3	3	4	4	5	6	1	2	3
4	4	11	2	3	4	1	2	3
5	1	5	2	4	5	2	2	2
6	5	6	3	3	6	2	2	2
7	6	7	20	20	20	2	2	2
8	7	11	3	4	4	3	3	3
9	1	8	2	3	4	2	2	2
10	8	9	2	2	2	1	2	2
11	9	10	13	14	15	2	2	2
12	10	11	2	3	4	1	2	2

RESOURCE TYPE	NOS.	OPTI. TIME	MOST LIKELY	PESSI. TIME
1	3	3	3	3
2	3	4	5	6
3	3	1	2	2

ACTIVITY NO.	START. NODE	END. NODE	OPTI. TIME	LIKELY TIME	PISSI. TIME	RESOURCES REQUIRMENT TYPE 1	TYPE 2	TYPE 3
1	1	3	5	11	14	2	4	3
2	1	5	1	5	7	5	4	2
3	3	7	0	0	0	0	0	0
4	3	9	4	5	7	0	2	1
5	3	13	8	12	20	2	4	4
6	5	7	0	0	0	0	0	0
7	5	11	8	14	16	2	2	2
8	7	17	3	6	9	3	1	1
9	9	15	6	11	16	2	3	2
10	11	15	2	4	6	4	3	5
11	11	19	4	9	10	4	5	1
12	13	17	7	10	11	1	2	5
13	13	21	14	16	18	3	2	1
14	15	17	4	8	9	1	2	2
15	15	19	6	12	18	3	2	3
16	17	21	5	7	14	2	3	1
17	19	23	2	4	10	5	2	1
18	21	23	2	7	8	2	2	2

RESOURCE TYPE	NOS.	OPTI. TIME	MOST LIKELY	PESSI. TIME
1	5	5	5	6
2	5	0	0	0
3	5	1	4	9

EXAMPLE 10

ACTIVITY NO.	START. NODE	END. NODE	OPTI. TIME	LIKELY TIME	PISSI. TIME	RESOURCES REQUIRMENT TYPE 1	TYPE 2	TYPE 3
1	1	2	5	6	10	2	2	2
2	1	3	4	8	10	1	2	0
3	2	5	4	9	11	3	2	0
4	2	8	15	17	19	2	2	2
5	3	4	2	4	6	2	1	1
6	3	5	2	3	6	3	3	3
7	4	5	4	9	10	2	1	2
8	4	6	15	17	28	2	3	1
9	4	7	9	11	14	2	2	1
10	5	6	2	4	6	2	1	2
11	5	8	3	6	9	2	2	2
12	6	9	4	5	6	2	1	1
13	6	12	2	4	5	1	2	2
14	7	13	3	5	7	2	2	2
15	8	9	4	5	6	1	2	1
16	8	10	2	3	6	1	1	1
17	8	11	3	4	5	2	2	1
18	9	11	2	4	8	1	0	0
19	10	13	2	5	6	1	2	2
20	11	14	5	6	8	1	2	2
21	12	13	4	7	8	1	2	2
22	13	14	5	7	9	1	1	1

RESOURCE TYPE	NOS OF	OPTIM TIME	MOST LIKELY	PESSI. TIME
1	3	4	5	6
2	3	2	6	7
3	3	1	1	4

```
        DATA "THE ACTUAL CASE"
        DATA "R1 HIRED"
        DATA "R2 HIRED"
        DATA "R3 HIRED"
        DATA "R1&R2 HIRED"
        DATA "R1&R3 HIRED"
        DATA "R2&R3 HIRED"
        DATA "R1,R2&R3 HIRED"
        DATA "SHIFT BY B/4"
        DATA "SHIFT BY 2B/4"
        DATA "SHIFT BY 3B/4"
        DATA "SHIFT BY B"

REM     MAIN PROGRAM

REM     THE SOFTWARE PROGRAM SOLVES A PROJECT MANAGEMENT   PROBLEM ,THIS
REM     SOFTWARE INCOROPARATE THE STOCHASTIC AVAILABILITY OF THE RESOURCE
S
REM     OF ACTIVITY NUMBER,STARTING NODE,ENDING NODE AND THE TIME DURATION
REM     OF THE ACTIVITY.

REM     THE PROGRAM THEN REARREANGES THE INPUT ACTIVITIES ACCORDING TO PRE-
REM     CEDENCE AND CALCULATES THE EARLY START,EARLY FINISH,LATE START,LATE
REM     FINISH,TOTAL FLOAT & FREE FLOAT OF EACH ACTIVITY.IT ALSO  INDICATES
REM     EACH CRITICAL ACTIVITY.

REM     SOFTWARE SPECIFICATIONS :
REM     -----------------------

REM     1 - THE PROGRAM IS WRITTEN IN BASIC LANGUAGE.
REM     2 - THE PROGRAM IS USER FRIENDLY & MENU DRIVEN.
REM     3 - THE PROGRAM HAS THE OPTION TO ENTER A NEW PROBLEM OR ACCEPT
REM         ALREADY EXISTING PROBLEMS
REM     4 - THE PROGRAM HAS THE FACILITY TO  CORRECT   WRONG INPUT DATA
REM     5 - THE OUTPUT OF THE PROGRAM CAN BE   DISPLAYED ON THE   SCREEN
REM         AND/OR SENT IT TO THE PRINTER.
REM     6 - THE INPUT DATA AND THE OUTPUT ARE DISPLAYED IN A TABULAR   FORM
REM         TEN ACTIVITIES AT A TIME,WHICH ENABLES THE USER TO EXAMINE EACH
REM         ACTIVITY EASILY.


       CLS:LOCATE 5,1
       COLOR 2,0,1
       PRINT TAB(20);"THE INDUSTRIAL ENGINEERING DEPARTMENT"
       PRINT TAB(29);"JORDAN UNIVERSITY"
       LOCATE 15,1:PRINT:PRINT TAB(16);"PROJECT MANAGEMENT BY THE CRITICAL PATH M
       PRINT:PRINT:PRINT:PRINT TAB(33);"MAY 1991"
       FOR I=1 TO 5000:NEXT I
       CLS
       LOCATE 5,15
       PRINT "THE SOFTWARE WAS DEVELOPED TO SOLVE A CPM NETWORK BY"
       PRINT TAB(15)"CALCULATING EARLY START (ES) AND FINISH TIMES , LATE"
       PRINT TAB(15)"START (LS) AND FINISH TIMES,TOTAL & FREE FLOATS  .  "
       PRINT:PRINT TAB(15) "TOTAL FLOAT IS THE TIME ANY GIVEN TASK MAY BE DELAYE
```

```
        PRINT TAB(15)"BEFORE IT WILL AFFECT THE PROJECT  COMPLETION TIME"
        PRINT:PRINT TAB(15)"FREE FLOAT IS THE TIME ANY TASK MAY BE DELAYED BEFORE"
        PRINT TAB(15)"IT WILL AFFECT THE EARLIEST STARTING DATE  OF   TASKS"
        PRINT TAB(15)"IMMEDIATELY FOLLOWING"

        PRINT:PRINT TAB(15)"THE OUTPUT SOLUTION IS DISPLAYED IN A TABULAR FORM"
        PRINT:PRINT:
        PRINT TAB(55)"HIT ENTER TO CONTINUE"
        INPUT X
        CLS
        LOCATE 5,15
        PRINT "THE SOFTWARE IS DESIGNED TO BE USER FRIENDLY AND MENU DRIVEN"
        PRINT :PRINT TAB(15) "IT HAS THE CAPABILITY OF READING ALREADY EXISTING FILES
        PRINT:PRINT TAB(15) "SAVING NEW FILES."
        PRINT:PRINT TAB(15) "THE SOFTWARE PROVIDES THE USER WITH THE  FACILITY TO DI
        PRINT:PRINT TAB(15) "THE OUTPUT SOLUTION ON THE SCREEN OR TO OBTAIN A  HARD
        PRINT:PRINT TAB(15) "ON THE PRINTER."
        PRINT:PRINT TAB(15) "THE STARTING NODE MUST BE >= 1"
        PRINT:PRINT TAB(15) "NOTE THAT : THE NETWORK NODES MUST BE CONNECTED TOGETH
        PRINT:PRINT:PRINT TAB(55) "HIT ENTER TO CONTINUE"
        INPUT X
        DIM B(300,11)
        DIM A(150,16)
        DIM AA(150,2)
        DIM AAA(1000)
        DIM E(50)
        DIM S(50)
        DIM P(1000,4)
        DIM ALT(12,5)
        DIM HC(3)
        DIM A$(12)
        D$="####.##"
1       SCREEN 0
        COLOR 1,7,7
        CLS: LOCATE 5,5
        PRINT TAB(10);"CHOOSE ONE OF THE FOLLOWING :-"
        PRINT:PRINT:PRINT:
        PRINT TAB(10);"1- SOLVE STOCHASTIC RESOURCES & ACTIVITIES SCHEDULING"
        PRINT TAB(13);"PROJECT."
        PRINT TAB(10);"2- CHOOSE THE BEST AVAILABLE ALTERNATIVE."
        PRINT TAB(10);"3- EXSIT TO SYSTEM."
5454    INPUT LL
        IF LL=1 THEN 4545
        IF LL=2 THEN 4545
        IF LL=3 THEN 30000
        BEEp
        PRINT:PRINT:PRINT "ENTER CORRECT CHOISE NUMBER."
        GOTO 5454
4545    SCREEN 0
        COLOR 1,7,7
        CLS: LOCATE 5,5
        IF LL=2 THEN 4541
        PRINT TAB(5);"ENTER NUMBER OF ALTERNATIVE REQIRED"
        INPUT KM
4541    SCREEN 0
        COLOR 1,7,7
```

```
        CLS:LOCATE 5,5
        PRINT TAB(10);"CHOOSE ONE OF THE FOLLOWING : "
        PRINT:PRINT:PRINT:
        PRINT TAB(15);"1 - ENTER NEW PROBLEM "
        PRINT TAB(15);"2 - READ AN EXISTING PROBLEM"
22000   INPUT L
        IF L = 1 THEN 18000
        IF L = 2 THEN 15000
        BEEP
        PRINT:PRINT:PRINT"ENTER CORRECT CHOICE NO. !"
        GOTO 22000

18000   SCREEN 0
        COLOR 1,7,7
        CLS
        PRINT "ENTER PROJECT NAME"
        INPUT A$
        PRINT "ENTER SUPERVISOR NAME"
        INPUT L$
        PRINT "ENTER NUMBER OF ACTIVITIES"
        INPUT N
        DIM RR(6)
11999   FOR I=1 TO 3
        COLOR 1,7,7
        CLS
        PRINT:
        PRINT:
        PRINT:
1199    PRINT "ENTER NUMBER OF RESOURCES AVAILABLE OF TYPE";I
        INPUT A(I+N,1)
        PRINT "ENTER THE OPTIMESTIC AVAILABILITY TIME OF RESOURCE TYPE";I
        INPUT A(I+N,10)
        PRINT "ENTER THE MOST LIKELY AVAILABILITY TIME OF RESOURCE TYPE ";I
        INPUT A(I+N,11)
        IF A(I+N,10)>A(I+N,11) THEN 1166
        PRINT "ENTER THE PISSIMISTIC AVAILABILYTY TIME OF RESOURCE TYPE ";I
        INPUT A(I+N,12)
        IF A(I+N,11)>A(I+N,12) THEN 1166
        GOTO 2255
1166    BEEP
        PRINT:PRINT "THE IPTIMESTIC TIME MUST BE < THE MOST LIKELY <PESSIMISTIC
        GOTO 1199
2255    IF A(I+N,11)=A(I+N,12) THEN 1133
        GOTO 1155
1133    IF A(I+N,10)=A(I+N,12) THEN 1144
        GOTO 1155
1144    A(I+N,16)=1
1155    NEXT I
        IF XXX =1 THEN  1000
        PRINT :
        FOR I= 1 TO N
        GOSUB 111
        NEXT I
        GOTO 2000
111     CLS
        PRINT :
```

```
        PRINT "FOR ACTIVITY NUMBER ";I
        PRINT :

7000    PRINT "NUMBER OF STARTING NODE = ";
        INPUT A(I,1)
        PRINT :
        PRINT "NUMBER OF THE ENDING NODE = ";
        INPUT A(I,2)
        PRINT :
        IF A(I,2) > A(I,1) THEN 8000
        BEEP
        PRINT:
        PRINT "WRONG ENTRY ; NO.OF ENDING NODE MUST BE LARGER THAN"
        PRINT "THE NO.OF THE STARTING NODE ! RETRY "
        PRINT:
        GOTO 7000
        PRINT:
8000    PRINT "THE OPTIMESTIC ACTIVITY TIME = ";
        INPUT A(I,10)
        PRINT:
        PRINT "THE MOST LIKELY ACTIVITY TIME = ";
        INPUT A(I,11)
        PRINT:
        PRINT " THE PESSIMISTIC ACTIVITY TIME = ";
        INPUT A(I,12)
        IF A(I,12)>= A(I,11) THEN 32
        BEEP
        PRINT:
        PRINT:
        PRINT "WRONG ENTRY; THE PESSIMISTIC TIME MUST BE GREATER OR "
        PTINT:
        PRINT "EQUAL TO THE MOST LIKELY TIME."
        GOTO 8000
32      IF A(I,11)> A(I,10) THEN 33
        IF A(I,11) = A(I,10) THEN 34
        BEEP
        PRINT " WRONG ENTRY; THE MOST LIKELY TIME MUST BE GREATER OR"
        PRINT:
        PRINT " EQUAL TO THE OPTIMISTIC TIME."
        GOTO 8000
34      IF A(I,12)>A(I,11) THEN 33
        A(I,16)=1
33      FOR J =1 TO 3
        PRINT:
        PRINT " RESUORCE REQUIRMENT OF TYPE ";J;" =";
        INPUT A(I,12+J)
        NEXT J
        RETURN
2000    CLS
        COLOR 14,1,0
        PRINT TAB(5);"ENTER NUMBER OF SIMULATION"
        INPUT ZZ

        SCREEN 0
        COLOR 14,1
```

```
17000   CLS
        COLOR 14,1,0
        PRINT :PRINT "PROJECT NAME : ";A$
        PRINT"SUPERVISOR NAME : ";L$
        PRINT:PRINT:PRINT:
        PRINT " ACTIVITY";TAB(11);"START.";TAB(20);"END.";TAB(27);"OPTI.";TAB(36);"LIKELY";T
        PRINT "   NO."; TAB(11);"NODE";TAB(20);"NODE";TAB(27);"TIME";TAB(36);"TIME";TAB(45);
        PRINT TAB(55);"TYPE 1";TAB(63);"TYPE 2";TAB(71);"TYPE 3"
        PRINT : PRINT  "----------------------------------------------------------------------
        PRINT:PRINT:

        J = 10
        FOR R = 1 TO N
        FOR I=R TO J
        PRINT TAB(4);I;TAB(12);A(I,1);TAB(21);A(I,2);TAB(28);A(I,10);TAB(37);A(I,11);TAB(46);A(I,12
        IF I = N THEN 35000
        NEXT I
        R = I-1
        J = R+10
        PRINT:PRINT:PRINT:
        COLOR 7,1
        print TAB(55)"HIT ENTER TO CONTINUE"
        INPUT X
        CLS:
        COLOR 14,1,0
        PRINT " ACTIVITY";TAB(11);"START.";TAB(20);"END.";TAB(27);"OPTI.";TAB(36);"LIKELY";T
        PRINT "   NO.";TAB(11);"NODE";TAB(20);"NODE";TAB(27);"TIME";TAB(36);"TIME";TAB(45);"
        PRINT TAB(55);"TYPE 1";TAB(63);TYPE 2";TAB(71);"TYPE 3"
        PRINT "-----------------------------------------------------------------------------
        PRINT:PRINT:
        NEXT R

35000   PRINT:PRINT:PRINT:PRINT:
        PRINT "IS THE INPUT ACTIVITIES CORRECT ?(Y/N)"
        INPUT X$
        IF X$="Y" THEN 1000
        IF X$="y" THEN 1000
        COLOR 14,1,0
        PRINT :
        PRINT "ENTER TOTAL NO. OF WRONG ACTIVITIES =";
        INPUT T
        PRINT :
        FOR F=1 TO T
        CLS
        PRINT "ENTER ACTIVITY NUMBER. =";
        INPUT I
        GOSUB 111
        NEXT F
        GOTO 1000
1110    FOR I=1 TO N
        AA(I,1)=0
        AA(I,2)=0
        NEXT I
        FOR I=1 TO N+3
        GOSUB 8017
```

```
        NEXT I
        GOTO 16000
8017    IF A(I,16)=1 THEN 42
        K=(5*A(I,10)-4*A(I,11)-A(I,12))/(A(I,10)+4*A(I,11)-5*A(I,12))
        K2=(-K^2+34*K-1)/((K+1)^3)
        K1=K*K2
        X3=.1
        X2=A(I,12)-A(I,10)
        FOR J=2 TO 10
        X=(J-1)*X3
        F(X)=X^(K1-1)*(1-X)^(K2-1)
        B(2*I,J)=F(X)
        B(2*I-1,J)=A(I,10)+(J-1)*.1*X2
        NEXT J
        B(2*I,1)=B(2*I,2)/4
        B(2*I,11)=B(2*I,10)/4
        B(2*I-1,1)=A(I,10)
        B(2*I-1,11)=A(I,12)
        FOR J=1 TO 11
        B(2*I,J)=B(2*I,J-1)+B(2*I,J)
        NEXT J
        FOR J=1 TO 11
        B(2*I,J)=B(2*I,J)/B(2*I,11)
        NEXT J
        GOTO 43
42      FOR J= 1 TO 10
        B(2*I,J)=1
        B(2*I-1,J)=A(I,10)
        NEXT J
43      RETURN
        GOTO 16000
REM      MENU 1
1000    SCREEN 0
        COLOR 1,7,7
        CLS
        PRINT :PRINT:PRINT:
        PRINT TAB(2);"RESOURCE TYPE";TAB(17);"NOS.";TAB(23);"OPTI. TIME";TAB(36);"MOST LI
        PRINT TAB(2);"-------------";TAB(17);"----";TAB(23);"----------";TAB(36);"----------"
        FOR I=1 TO 3
        PRINT TAB(9);I;TAB(18);A(I+N,1);TAB(29);A(I+N,10);TAB(40);A(I+N,11);TAB(54);A(I+N,12)
        NEXT I
        PRINT "IS THE INPUT RESOURCES CORRECT ? (Y,N)"
        INPUT M$
        IF M$="Y" THEN  9999
        IF M$="y" THEN  9999
        CLS:
        LOCATE 5,1
        PRINT TAB(5);"REINPUT THE RESOURCES DATA"
        XXX=1
        GOTO 11999
9999    SCREEN 0
        COLOR 1,7,7
        CLS:LOCATE 5,1
        FOR I=1 TO 3
        PRINT:
        PRINT TAB(5);"THE HIRED COST OF RESOURCE TYPE ";I;" =";HC(I)
```

```
        NEXT I
        PRINT:PRINT TAB(5);"THE OVER HEAD COST PER UNIT TIME =";OH
        PRINT:PRINT TAB(5);"THE PENALTY COST PER UNIT TIME =";PC
        PRINT:PRINT TAB(5);"THE SCHEDULING DATE =";TSCH
        PRINT:PRINT:PRINT TAB(5);"IS THE COST FACTORS CORRECT ? ( Y,N) "
        INPUT K$
        IF K$="Y" THEN 7788
        IF K$="y" then 7788
        GOTO 6464
7788    SCREEN 0
        COLOR 1,7,7
        CLS:LOCATE 5,1
4646    PRINT TAB(10);"CHOOSE ONE OF THE FOLLOWING :"
        PRINT :PRINT:PRINT:
        PRINT TAB(15);"1 - SAVE THE PROBLEM"
        PRINT TAB(15);"2 - SOLVE THE PROBLEM"
        PRINT TAB(15);"3 - RETURN TO MAIN MENU"
24000   INPUT L
        IF L = 1 THEN 14000
        IF L = 2 THEN 1110
        IF L = 3 THEN 1
        BEEP
        PRINT :PRINT:PRINT" ENTER CORRECT CHOICE NO. !"
        GOTO 24000
16000   FOR I=1 TO N
        A(I,3)=(A(I,10)+A(I,11)*4+A(I,12))/6
        NEXT I
        N1 = 0
        FOR I=1 TO N
        IF A(I,2) > N1 THEN 6
        GOTO 4
  6     N1 = A(I,2)
  4     NEXT I
        FOR K= 1 TO N1
        FOR I =1 TO N
        M = 0
        IF A(I,1)<>K THEN 40
        IF K = 1 THEN 30
        M = M+1
        IF M>1 THEN 20
        A(I,4) = 0
        FOR J = 1 TO N
        IF A(I,1)<>A(J,2) THEN 10
        IF A(J,5) < A(I,4) THEN 10
        A(I,4) = A(J,5)
        X = A(I,4)
 10     NEXT J
 20     A(I,4)= X
        A(I,5) = A(I,4) + A(I,3)
        GOTO 40
 30     A(I,4) = 0
        A(I,5) = A(I,3)
 40     NEXT I
        NEXT K
        X = 0
```

```
        FOR I = 1 TO N
        IF A(I,2)<>N1 THEN 60
        IF A(I,5) < X THEN 60
        X = A(I,5)
        Y=X
60      NEXT I
        FOR O= 1 TO N1
        K = N1+1-O
        M = 0
        FOR J = 1 TO N
        IF A(J,2)<> K THEN 70
        IF A(J,2)<>N1 THEN 80
        A(J,7) = X
        A(J,6) = A(J,7) - A(J,3)
        GOTO 70
80      M= M+1
        IF M>1 THEN 100
        A(J,7)=Y
        FOR I=1 TO N
        IF A(I,1)<> A(J,2) THEN 90
        IF A(I,6) >A(J,7) THEN 90
        A(J,7)= A(I,6)
        X=A(J,7)
90      NEXT I
100     A(J,7) = X
        A(J,6) = A(J,7) - A(J,3)
70      NEXT J
        NEXT O
        FOR I = 1 TO N
        A(I,8) = A(I,7)-A(I,5)
        FOR J=1 TO N
        IF A(I,2)=N1 THEN 160
        IF A(I,2)=A(J,1) THEN 150
        NEXT J
        GOTO 170
150     A(I,9)=A(J,4)-A(I,5)
        GOTO 170
160     A(I,9)=Y-A(I,5)
170     NEXT I
        GOTO 29001
29000   SCREEN 0
        COLOR 1,7,7
        CLS:LOCATE 5,1
        PRINT TAB(10);"CHOOSE ONE OF THE FOLLOWING :"
        PRINT:PRINT:PRINT:
        PRINT TAB(15);"1 - DISPLAY SOLUTION ON SCREEN "
        PRINT TAB(15);"2 - PRINT SOLUTION "
        PRINT TAB(15);"3 - SOLVE PROBLEM"
        PRINT TAB(15);"4 - RETURN TO PREVIEST MENU"
        PRINT TAB(15);"5 - RETURN TO MAIN MENU"
26000   INPUT L
        IF L = 1 THEN 25000
        IF L = 2 THEN 20000
        IF L = 3 THEN 1110
        IF L = 4 THEN 1000
        IF L = 5 THEN 1
```

```
        BEEP
        PRINT:PRINT:PRINT"ENTER CORRECT CHOICE NO. !"
        GOTO 26000

25000   SCREEN 0
       IF LL<>2 THEN 6688
        COLOR 14,1,0
        CLS
        PRINT:
        PRINT TAB(3);"ALTERNATIVES";TAB(20);"MEAN";TAB(28);"STANDARD";TAB(40);"COST AT
        PRINT TAB(4);"AVAILABLE";TAB(28);"DEVIATION";TAB(41);"50%";TAB(48);"75%";TAB(56);"
        PRINT TAB(3);"-----------------------------------------------------------"
        FOR I =1 TO 12
        PRINT TAB(3);A$(I);USING D$;TAB(19);ALT(I,1);TAB(27);ALT(I,2);TAB(37);ALT(I,3);TAB(46)
        NEXT I
        PRINT TAB(3);"-----------------------------------------------------------"
        PRINT TAB(5);"WHERE B = ";BM;" UNITS OF TIME"
        PRINT TAB(3);"-----------------------------------------------------------"
        PRINT:PRINT:PRINT:
        PRINT "HIT RETURN TO CONTINUE:
        INPUT X
        GOTO 29000
6688    COLOR 14,1,0
        CLS
        PRINT:PRINT " PROJECT NAME : ";A$
        PRINT " SUPERVISOR NAME : ";L$
        PRINT:PRINT:PRINT:
        PRINT TAB(2);"ACTIVITY";TAB(18);"I";TAB(25);"J";TAB(35);"ES";TAB(45);"EF"
        PRINT TAB(2);"NUMBER"
        PRINT TAB(1);"---------";TAB(16);"----";TAB(24);"----";TAB(34);"----";TAB(44);"----"
        PRINT:
        J = 10
        FOR R = 1 TO N
        FOR I = R TO J
        PRINT TAB(4);I;USING D$;TAB(15);A(I,1);TAB(22);A(I,2);TAB(32);A(I,4);TAB(42);A(I,5)
        IF I = N THEN 40000
        NEXT I
        R = I - 1
        J = R + 10
        COLOR 7,1
        PRINT:PRINT:
        PRINT TAB(55) "HIT RETURN TO CONTINUE"
        INPUT X
        CLS:
        COLOR 14,1,0
        PRINT TAB(2);"ACTIVITY";TAB(18);"I";TAB(25);"J";TAB(35);"ES";TAB(45);"EF"
        PRINT TAB(2);"NUMBER"
        PRINT:
        PRINT TAB(1);"---------";TAB(16);"----";TAB(24);"----";TAB(34);"----";TAB(44);"----"
        PRINT:
        PRINT:
        NEXT R
40000   PRINT:PRINT:PRINT TAB(55);"HIT RETURN FOR STATISTICAL ANALYSIS"
        INPUT X
        CLS
        PRINT:PRINT:PRINT
```

```
       PRINT TAB(15);"STATISTICAL ANALYSIS FOR THE COMPLETION TIME"
       PRINT:PRINT TAB(25);"   OF THE PROJECT"
       PRINT:PRINT:PRINT:
       PRINT TAB(5);"NUMBER OF SIMULATION RUN = ";USING D$;ZZ
       PRINT:
       PRINT TAB(3);"THE MEAN OF THE COMPLETION TIME = ";USING D$;XY
       PRINT:
       PRINT TAB(3);"THE STANDARD DEVIATION TIME OF THE PROJECT =";USING D$;XZ
       PRINT:
       PRINT TAB(3);"THE 95% CONFIDENCE INTERVAL FOR THE COMPLETION TIME :(";XZ1;",";
       PRINT:
       PRINT TAB(3);"THE RANGE FOR THE COMPLETION TIME                  :(";XZ4;",";XZ
       PRINT:PRINT:PRINT TAB(45);"HIT RETURN FOR COST ANALYSIS"
       INPUT X
       CLS
       PRINT:PRINT:PRINT
       PRINT TAB(40);"COST ANALYSIE"
       PRINT:PRINT:PRINT
       PRINT TAB(15);"1- THE PROJECT COST AT 50% PERFORMANCE PROBABILITY = ";ALT(KM,
       PRINT
       PRINT TAB(15);"2- THE PROJECT COST AT 75% PERFORMANCE PROBABILITY = ";ALT(KM,
       PRINT
       PRINT TAB(15);"3- THE PROJECT COST AT 95% PERFORMANCE PROBABILITY = ";ALT(KM,
       PRINT:PRINT:PRINT TAB(50);"HIT RETURN TO CONTINUE"
       INPUT X
       GOTO 29000
30000  END

13000  BEEP
       PRINT :
       PRINT "WRONG ENTRY ; THE NO.OF THE ENDING NODE MUST BE LARGER THAN"
       PRINT "THE NO.OF THE STARTING NODE ! RETRY "
       PRINT:

20000  LPRINT:LPRINT " PROJECT NAME : ";A$
       LPRINT " SUPERVISOR NAME : ";L$
       LPRINT:LPRINT:LPRINT:
       LPRINT TAB(2);"ACTIVITY";TAB(18);"I";TAB(25);"J";TAB(35);"ES";TAB(45);"EF"
       LPRINT TAB(2);"NUMBER"
       LPRINT TAB(1);"-------";TAB(16);"----";TAB(24);"----";TAB(34);"----";TAB(44);"-----"
       LPRINT:
       FOR I=1 TO N
       LPRINT TAB(4);I;USING D$;TAB(17);A(I,1);TAB(24);A(I,2);TAB(34);A(I,4);TAB(44);A(I,5)
       NEXT I
       LPRINT:LPRINT:LPRINT
       LPRINT TAB(15);"STSTISTICAL ANALYSIS FOR THE CMPLETION TIME"
       LPRINT:LPRINT TAB(25);"OF THE PROJECT"
       LPRINT:LPRINT:LPRINT:
       LPRINT TAB(3);"NUMBER OF SIMULATION RUN = ";ZZ
       LPRINT:
       LPRINT TAB(3);"THE MEAN OF THE COMPLETION TIME OF THE PROJECT = ";USING D$;XY
       LPRINT:
       LPRINT TAB(3);"THE STSNDARD DEVIATION OF THE PROJECT = ";USING D$
```

```
        RR(6)=0
        FOR MMM= 1 TO 3
        P(K,MMM)=A(N+MMM,3)+P(K-1,MMM)
        NEXT MMM
        IF KM=1 THEN 8009
        IF KM=2 THEN 8001
        IF KM=3 THEN 8002
        IF KM=4 THEN 8003
        IF KM=5 THEN 8004
        IF KM=6 THEN 8005
        IF KM=7 THEN 8006
        IF KM=8 THEN 8007
8009    P(K,1)=0
        P(K,2)=0
        P(K,3)=0
        GOTO 7878
8001    A(N+1,3)=0
        P(K,2)=0
        P(K,3)=0
        GOTO 7878
8002    A(N+2,3)=0
        P(K,1)=0
        P(K,3)=0
        GOTO 7878
8003    A(N+3,3)=0
        P(K,1)=0
        P(K,2)=0
        GOTO 7878
8004    A(N+1,3)=0
        A(N+2,3)=0
        P(K,3)=0
        GOTO 7878
8005    A(N+1,3)=0
        A(N+3,3)=0
        P(K,2)=0
        GOTO 7878
8006    A(N+2,3)=0
        A(N+3,3)=0
        P(K,1)=0
        GOTO 7878
8007    A(N+1,3)=0
        A(N+2,3)=0
        A(N+3,3)=0
        GOTO 7878
8012    IF LL=2 THEN 10106
        IF KM=9 THEN 10101
        IF KM=10 THEN 10102
        IF KM=11 THEN 10103
        IF KM=12 THEN 10104
10101   SH=BM/4
        GOTO 10105
10102   SH=BM/2
        GOTO 10105
```

```
        E(O)=E(M)
        E(M)=Z
        GOTO 1016
1005    IF A(E(O),3) >= A(E(M),3) THEN 1016
        Z=E(O)
        E(O)=E(M)
        E(M)=Z
1016    NEXT M
1004    NEXT O
1015    FOR I=1 TO 3
        IF RR(I+3)=1 THEN 2003
        IF A(N+I,3)<=T THEN 2002
        GOTO 2003
2002    RR(I)=A(I+N,1)
        RR(3+I)=1
        T=A(N+I,3)
2003    NEXT I
0023    FOR J=1 TO Y
        IF RR(1)<A(E(J),13) THEN 1006
        IF RR(2)<A(E(J),14) THEN 1006
        IF RR(3)<A(E(J),15) THEN 1006
        A(E(J),4)=T
        A(E(J),5)=A(E(J),3)+T
        AA(E(J),1)=AA(E(J),1)+A(E(J),4)
        AA(E(J),2)=AA(E(J),2)+A(E(J),5)
        k11=1+k11
        X=X+1
        S(X)=E(J)
        IF Y=1 THEN 1019
        IF Y=J THEN 1019
        FOR I=J TO Y-1
        E(I)=E(I+1)
        NEXT I
1019    Y=Y-1
        RR(1)=RR(1)-A(S(X),13)
        RR(2)=RR(2)-A(S(X),14)
        RR(3)=RR(3)-A(S(X),15)
        GOTO 0023
1006    NEXT J
1010    T=T+1
         IF X<1 THEN 1015
        FOR I=1 TO 3
        IF RR(I+3)=1 THEN 3002
        IF A(N+I,3)<=T THEN 3003
        GOTO 3002
3003    RR(I)=A(I+N,1)
        RR(I+3)=1
        T=A(N+I,3)
3002    NEXT I
1024    FOR M=1 TO X
        IF A(S(M),5)=<T THEN 1007
        NEXT M
        GOTO 1010
1007    T=A(S(M),5)
        RR(1)=RR(1)+A(S(M),13)
        RR(2)=RR(2)+A(S(M),14)
```

```
        RR(3)=RR(3)+A(S(M),15)
        IF X=1 THEN 1021
        IF X=M THEN 1021
        Z2=A(S(M),2)
        FOR J=M TO X-1
        S(J)=S(J+1)
        NEXT J
        GOTO 1041
1021    Z2=A(S(M),2)
1041    X=X-1
        FOR J=1 TO N
        IF A(J,2)=Z2 THEN 1026
        GOTO 1025
1026    IF A(J,5)<=T THEN 1052
        GOTO 1028
1052   if a(j,5)>0 then 1025
       GOTO 1028
1025    NEXT J
        FOR J=1 TO N
        IF A(J,1)=Z2 THEN 1011
        GOTO 1012
1011    Y=Y+1
        E(Y)=J
        IF Y=1 THEN 1012
        FOR O=1 TO Y-1
        IF A(E(O),6)<A(E(Y),6) THEN 1022
        IF A(E(O),6)=A(E(Y),6) THEN 1013
        Z=O
        Z1=E(Y)
        GOTO 1014
1013    IF A(E(Y),3)>=A(E(O),3) THEN 1022
        Z=O
        Z1=E(Y)
1014    I1=0
        I2=0
        FOR I=O TO Y-1
        I1=I1+1
        I2=Y-I1
        E(I2+1)=E(I2)
        NEXT I
        E(Z)=Z1
        GOTO 1012
1022    NEXT O
1012    NEXT J
1028    FOR J=1 TO Y
        IF RR(1)<A(E(J),13) THEN 1017
        IF RR(2)<A(E(J),14) THEN 1017
        IF RR(3)<A(E(J),15) THEN 1017
        A(E(J),4)=T
        A(E(J),5)=T+A(E(J),3)
        AA(E(J),1)=AA(E(J),1)+A(E(J),4)
        AA(E(J),2)=AA(E(J),2)+A(E(J),5)
        k11=k11+1
        IF K11=N THEN 1018
        X=X+1
        S(X)=E(J)
```

```
        RR(1)=RR(1)-A(S(X),13)
        RR(2)=RR(2)-A(S(X),14)
        RR(3)=RR(3)-A(S(X),15)
        IF Y=1 THEN 1029
        IF J=Y THEN 1029
        FOR I=J TO Y-1
        E(I)=E(I+1)
        NEXT I
1029    Y=Y-1
        IF Y=0 THEN 1030
        GOTO 1028
1017    NEXT J
1030    GOTO 1024
1018    MMM=0
        FOR Q=1 TO N
        IF A(Q,5)<MMM THEN 3032
        MMM=A(Q,5)
3032    NEXT Q
        AAA(K)=MMM
        MMM=1000000
        FOR Q=1 TO N
        IF A(Q,4)>MMM THEN 3067

        MMM=A(Q,4)
3067    NEXT Q
        P(K,4)=MMM
        NEXT K
        FOR I=1 TO N
        A(I,4)=AA(I,1)/ZZ
        A(I,5)=AA(I,2)/ZZ
        NEXT I
        XX=0
        FOR K=1 TO ZZ
        XX=XX+AAA(K)
        NEXT K
        XY=XX/ZZ
        XZ=0
        FOR K=1 TO ZZ
        XZ=(AAA(K)-XY)^2+XZ
        NEXT K
        XZ=(XZ/(K-1))^1/2
        XZ1=XY-1.96*XZ
        XZ2=XY+1.96*XZ
        XZ3=0
        FOR K =1 TO ZZ
        IF AAA(K)>XZ3 THEN 12345
        GOTO 23456
12345   XZ3=AAA(K)
23456   NEXT K
        XZ4 =10^10
        FOR K=1 TO ZZ
        IF AAA(K)<XZ4 THEN 246
        GOTO 247
246     XZ4=AAA(K)
247     NEXT K
```

```
       CLS
       FOR M =1 TO 3
       P(ZZ,M)=P(ZZ,M)/ZZ
       NEXT M
       FOR M=1 TO ZZ
       P(M,4)=P(M,4)+P(M-1,4)
       NEXT M
       P(ZZ,4)=P(ZZ,4)/ZZ
       C1=P(ZZ,1)*HC(1)+P(ZZ,2)*HC(2)+P(ZZ,3)*HC(3)
       C2=(XY-P(ZZ,4))*OH
       C3=(XY+.575*XZ-P(ZZ,4))*OH
       C4=(XY+1.645*XZ-P(ZZ,4))*OH
       IF KM=9 THEN 3471
       IF KM=10 THEN 3472
       IF KM=11 THEN 3473
       IF KM=12 THEN 3474
       GOTO 3475
3471   XY=XY+BM/4
       GOTO 3475
3472   XY=XY+BM/2
       GOTO 3475
3473   XY=XY+3*BM/4
       GOTO 3475
3474   XY=XY+BM
3475   P1=(XY-TSCH)*PC
       IF P1<0 THEN 5555
       GOTO 5554
5555   P1=0
5554   P2=(XY+.575*XZ-TSCH)*PC
       IF P2<0 THEN 5553
       GOTO 5552
5553   P2=0
5552   P3=(XY+1.645*XZ-TSCH)*PC
       IF P3<0 THEN 5551
       GOTO 5550
5551   P3=0
5550   ALT(KM,1)=XY
       ALT(KM,2)=XZ
       IF KM<9 THEN 4442
       C1=0
4442   ALT(KM,3)=C1+C2+P1
       ALT(KM,4)=C1+C3+P2
       ALT(KM,5)=C1+C4+P3
       IF LL<>2 THEN 10107
       NEXT KM
       CLS
       FOR I=1 TO 12
       READ A$(I)
       NEXT I
10107  GOTO 29000
14000  PRINT "ENTER NEW FILE NAME "
        INPUT M$
        OPEN"O",#1,M$
        PRINT#1,N
        PRINT#1,A$
```

```
      PRINT#1,L$
      FOR I=1 TO N+3
      PRINT#1,A(I,1)
      PRINT#1,A(I,2)
      PRINT#1,A(I,10)
      PRINT#1,A(I,11)
      PRINT#1,A(I,12)
      PRINT#1,A(I,13)
      PRINT#1,A(I,14)
      PRINT#1,A(I,15)
      PRINT#1,A(I,16)
      NEXT I
      FOR I=1 TO 3
      PRINT#1,HC(I)
      NEXT I
      PRINT#1,OH
      PRINT#1,PC
      PRINT#1,TSCH
      CLOSE#1
      GOTO 9999

15000 PRINT "ENTER FILE NAME "
      INPUT N$
REM       ON ERROR GOTO 55
      OPEN "I",#1,N$
      INPUT#1,N
      INPUT#1,A$
      INPUT#1,L$
      FOR I = 1 TO N+3
      INPUT#1,A(I,1)
      INPUT#1,A(I,2)
      INPUT#1,A(I,10)
      INPUT#1,A(I,11)
      INPUT#1,A(I,12)
      INPUT#1,A(I,13)
      INPUT#1,A(I,14)
      INPUT#1,A(I,15)
      INPUT#1,A(I,16)
      NEXT I
      FOR I=1 TO 3
      INPUT#1,HC(I)
      NEXT I
      INPUT#1,OH
      INPUT#1,PC
      INPUT#1,TSCH
      CLOSE #1
      OO=5
      GOTO 2000
55    PRINT:PRINT:PRINT "FILE NOT FOUND"
      PRINT:PRINT "HIT ENTER TO CONTINUE"
      INPUT X
      GOTO 1
6464  OO=1
      FOR KK= 1 TO 3
      PRINT:
      PRINT TAB(5); "ENTER THE HIRED COST OF RESOURCE TYPE ";KK;"PER UNIT TIME."
```

```
INPUT HC(KK)
NEXT KK
PRINT:PRINT:PRINT "ENTER THE OVERHEAD COST PER UNIT TIME."
INPUT OH
PRINT:PRINT:PRINT "ENTER THE PENALTY COST PER UNIT TIME."
INPUT PC
PRINT:PRINT:PRINT "THE SCHEDULING DATE."
INPUT TSCH
CLS:LOCATE 5,1
GOTO 4646
END
```