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THE USE AND BEHAVIOUR OF HEURISTICS IN CONSTRAINED RESOURCE PROJECT SCHEDULING

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UNDER THE SUPERVISION OF

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الخلاصة

استهدفت هذه الأطروحة تقصي إمكانيّة إيجاد علاقة رياضيّة ما بين أداء الطّرق التنقيبيّة المستخدمة في الجدولة الزمنيّة للمشاريع محدودة الموارد، وبين السمات المميّزة لشبكات تلك المشاريع. حيث يمكن استخدام هذه العلاقة في معرفة أيّ الطّرق التنقيبيّة تصلح في جدولة أيّ المشاريع المنفردة، وصولا الى اقل مدّة للمشروع عند وجود نوع أو أكثر من الموارد محدودة الوفرة.

بسبب الخاصيّة التوافقيّة المركّبة لشبكات المشاريع، فإنّ الطّرق المثلى في الجدولة الزمنيّة صعبة الاستخدام. وعليه، فإن الطّرق التنقيبيّة تستعمل كبديل فعّال و مناسب عن تلك الطّرق المثلى. إلاّ أنّ هذه الطّرق التنقيبيّة متفاوتة في أدائها مقارنة بالجداول الزمنيّة المثلى. وعليه فمن الضروريّ القيام ببحث شامل ومتكامل عن استخدام وتصرف هذه الطّرق.

ست طرق تنقيبيّة استخدمت في دراسة العلاقة ما بين أدائها وبين قيم السمات المميّزة العشر المختارة: خمس سمات مميّزة للوقت، أربع سمات مميّزة للموارد، وسمة واحدة مميّزة للشكل. وقد تمّ برمجة الخطوات المختلفة في البحث باستخدام لغة الحاسوب "تيربوبيسك" (Turbo Basic)، وسميّ برنامج الحاسوب (ReALL-1). مائة وخمسة وثلاثون مشروعا تجريبيّ، يحملون قيما مختلفة للسمات المميّزة العشر، تمّت جدولتهم زمنيّا باستخدام الطّرق التنقيبيّة المقترحة.

طرق إحصائية مختلفة تمّ اتّباعها في تحليل النتائج المستخرجة. فقد أمكن بناء نماذج رياضيّة توضّح العلاقة ما بين وبين السمات المميّزة العشر. وقد تمّ فصل تأثير السمات المميّزة للوقت عن تأثير السمات المميّزة للموارد. ومن ثمّ درست العلاقة الرابطة للسمة المميّزة للشكل والتأخير الزمنيّ في انهاء المشروع بشكل منفصل. حيث أظهرت النتائج إنخفاض مدى تأثير هذه السمة على التأخير الحاصل على مدّة انتهاء المشروع تحت الجدولة الزمنيّة.

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إنّ النتائج المستخلصة من الأطروحة قد بيّنت أنّ مدّة التأخير في انجاز المشروع أكبر عند وجود قيما كبيره نسبيّا للسمات المميّزة للموارد. بينما كانت مدّة التأخير تلك أقل عند وجود قيما كبيره نسبيّا للسمات المميّزة للوقت. وقد ظهر جليّا أنّ المشاريع التي تتطلب كميّات كبيرة من الموارد المحدوده نسبة الى الكميّة المتوفرة، لا تفرّق في عملية إنتقاء الطريقة التنقيبيّة الأنسب للجدولة الزمنيّة.

لقد أشارت النتائج إلى أهميّة إنتقاء طرّق تنقيبيّة أخرى، وسمات مميّزة مختلفة، ووضع أهداف متنوعة للجداول الزمنيّة المتوخّاه، اضافة الى مدّة التأخير في إتمام المشاريع، تسهيلا في عملية الاختيار الأسلم بين الطرّق التنقيبيّة المتاحة.

لقد كان من الأهمية بمكان وجود برنامج للحاسوب يمكّن الباحث من دراسة عدّة طرق تنقيبيّة بسهولة ودقّة وصولا الى نتائج أعم وأشمل.

لقد احتوت هذه الاطروحة على جداول النتائج المستخرجة بالاضافة الى قائمة المراجع التي يسّرت البحث والدراسة.

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ABSTRACT

The research aimed at examining the potential existence of a mathematical relationship between the performance of heuristics used in scheduling constrained resource projects, and the characteristic features (summary measures) of such projects networks. Such a relationship which selects a certain heuristic to schedule a single project with minimum duration of multiple and fixed requirements of constrained resources.

Due to the combinational nature of projects networks, optimal solutions are difficult to attain. Therefore, heuristics are used as an amenable substitute for optimal procedures. Yet, heuristics may not always produce a near-optimal solution, which dictates a through research on their use and behavior.

Six commonly used heuristics are investigated for their performance relative to ten selected summary measures; five resource-related measures, four time-related measures, and a shape-related measure. The different stages of the research were programmed using Turbo Basic Language. The program was named (ReALL-1). One hundred and thirty five Testnetworks carrying different summary measures values were scheduled using the proposed heuristics.

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Different statistical procedures were adopted to analyze the results obtained. Using multiple linear regression, six mathematical models were constructed, relating the delay in project termination date, due to the requirement of constrained resources by different project activities, with the ten summary measures. The effect of time-related measures on the heuristic performance was separated from the effect of resource-related measures. The shape-related measure was related linearly to heuristic performance, and proved to possess relatively low impact on the performance.

The results of the thesis indicated that projects of relatively high values of resource-related measures are expected to terminate at late dates if compared to projects of time-related measures prevalence. It was evident that "tight" projects (requiring large amount of constrained resources when compared to the available amounts) do not discriminate among heuristics, and less critical becomes the choice of a heuristic. Also, the results indicated the importance of testing other different heuristics, summary measures, and objectives of schedules, in order to facilitate the choice of appropriate heuristics in scheduling different projects. The importance of an efficient and accurate software was also made clear in arriving at a more well established mathematical relationship.

The thesis contained tables of all data obtained, and a list of the references used in the research.

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CHAPTER ONE
INTRODUCTION

Techniques for the management of resources in project planning and scheduling have received an increasing attention in recent years. Resource allocation, an important technique in this field, balances the need with availability of resources at a given time, and classifies project scheduling procedures into two categories: Heuristic Procedures and Optimal Procedures.

Heuristics, the main concern of this thesis, develop rapidly and need adequate research on designing, analyzing, and implementing such procedures.

1.1 Importance of Heuristics

A heuristic is a rule of thumb, simple, easy to use, guide or aid, used in problem-solving situations, to reduce the amount of effort required in coming up with a solution. Heuristics may not always produce the best solution in every case, but their usefulness in finding good solutions with a minimum effort is well-known, based on experience and research studies [5,10,13].

In recent years, a great deal of work has been done in resource allocation using heuristic methods and optimal procedures. Both approaches implicitly assume that resource availability, whether limited or unlimited, is certain [2]. There are in existence today a number of different heuristic-based

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procedures [7]. And to name a few of the commonly used heuristics: Activity control time (ACTIM), time*resource (TIMRES), minimum job slack (MINSLK), greatest resource demand (GRD), shortest imminent operation (SIO), resource scheduling method (RSM), minimum late finish time (LFT), selection at random (RAN), greatest resource utilization (GRU), most jobs possible (MJP).

Alternatively, optimal approach utilizes either linear or dynamic programming, or enumeration and other mathematical techniques. Due to excessive computation requirement, these techniques cannot easily and favorably be adopted for projects requiring a large number of resource types[13].

1.2 Project Scheduling

A project is a set of interrelated tasks or activities that must be executed to achieve certain planned objectives, and is usually distinguished from repetitive or continuous production process by the unique nature of the objective. Projects originate because something not done, developed, constructed, or produced before needs to be fulfilled [14]. Consequently, the management responsible for the attainment of project objective(s), must introduce a plan which regulates the relationships among interrelated tasks or activities, and the way for executing them, especially when alternative plans are being considered.

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As the activities durations are induced upon the proposed plan, project scheduling will undoubtedly be initiated. A successful planning and scheduling of a project understandably, correlates the three major dimensions of a project: Time, Cost, and Performance [18]:

- Project scheduling is the part of planning through which time element is significantly appreciated.

- When project duration is determined using the appropriate scheduling procedure, the question raised in the next step would be whether the current plan satisfies the relation between project duration and total project cost. It has always been the case to try to seek for a schedule that minimizes the total project cost; direct plus indirect. Determination of most economical project duration is highly likely to re-schedule some of the project activities using the concept proposed by Kelly and Walker: Time-cost trade-off procedure [1,12,13].

- Performance, the third dimension of planning, is a relative measure which seeks to observe the fulfillment of tasks and activities on the planned time, at most economical cost, and adhering to quality, during the whole project duration[18].

Project planning is also carried out using graphical portrayal of the dependency relationships among the project activities. Such a graph, called a network, uses the simple logic that all activities preceding a given activity must be completed before the given activity can begin [13].

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1.3 Resource Requirement and Allocation

The term resource is used for items required to allow for project completion. Typical resources include manpower, money, space, equipment, parts, supplies [5]. Even if sufficient resources are available to allow a theoretical schedule to be achieved, how those resources are scheduled can affect implementation cost. Whereas, imposing capacity or resource restriction of some kind, on project activities may lead to an increased completion time of the project.

Each project activity has specified requirements of one or more resource types, therefore, scheduling decisions are generally subject to both dependency relationship among activities, and resource constraints. The abundancy of resources falls into two distinct categories:

1. If resources are limited with an upper ceiling on the number of resource units, they are called Limited Resources. The scheduling objective of this category is to balance need with availability of resources, with a potential increase in project duration.

2. If there are no constraints imposed on the amount of resources, then these resources are called Unlimited Resources. Here, the scheduling objective of the second category is to assign the required amount of resources, preferably at a steady rate of seizing such resources, within a prescribed project

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duration.

Resource allocation answers the question whether resources are adequate to carry out the project tasks and activities, and schedule project activities by utilizing available resources at every time period [2,7,13]. It is dealt with in the first category stated previously.

Conventional resource allocation is carried out by trial and error, and is repeated till either all resources are exhausted, or the desired project duration is achieved; which ever occurs first [2]. Allocating limited resources is called Constrained Resource Scheduling, and this technique is adopted when the fixed amounts of resources available during each time period is not sufficient to satisfy demands of some concurrent activities. Therefore an increase in the theoretical project duration (final schedule still undetermined) is expected when such limited resources are allocated.

On the other hand, dealing with unlimited resources, the problem would be to minimize the number of resource units utilized while meeting the required schedule time. Therefore, resource leveling is a technique used to determine the amount of unlimited resources needed throughout the whole project duration, and to arrive at a better distribution of resource usage.

From what have been stated earlier, resource allocation is an

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essential part of practical planning, which can be translated into actual work by project scheduling.

1.4 Problem Definition

The problem to be investigated in this thesis is to determine if there exists a relationship between the use of a certain heuristic and the characteristic features of a project network. Such a relationship, which can suggest which heuristic to use for which project, is studied under the use of heuristics in scheduling the activities of a single project. The objective is to minimize the project duration under conditions of single or multiple and fixed resource requirements, assuming constrained resource availabilities.

1.5 Methodology

The Work scheme of this thesis has been designed as follows:

First; to use a well-known heuristics, and develop others by combining two non-conflicting heuristics, in order to study their behavior when used to schedule different projects. The heuristics are programmed using Turbo Basic.

Second; to generate hypothetical project networks (these generated networks are called Testnetworks in this thesis), which depict different characteristic features of networks, such as their length, complexity, resource demand, ... etc.

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Third; to schedule the Testnetworks using the proposed heuristics to determine the kind of relationship existing between heuristics and project characteristic features.

Fourth; to apply multiple linear regression to study the statistical aspect of the problem, and to detect any inherent relationship between heuristic performance and the characteristic features of a project network. Characteristic features serve as the independent variables of the regression model, and the expected delay in project termination serves as the response or the dependent variable.

Fifth; to analyse such models and predict the use and behaviour of heuristics in constrained project sheduling.

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CHAPTER TWO
LITERATURE REVIEW

The concept of scheduling time began as early as the need for planning. Today, though, we are forced by the complexities of modern living to establish very elaborate schedules in order to carry out the functions of society.

2.1 Critical Path Method (CPM)

During World War I, Henry L. Gantt developed a display for production control which was basically a bar chart upon which specific time points were indicated. This device has continued to be one of the most direct and easily understood methods for expressing project plans [12]. In 1931 a Polish Scientist, named Karol Adamiecki, developed and published a methodology in a form called Harmonygraph. This is a 90-degree rotated bar chart graph with a vertical time scale, and a column for each activity in the project [13].

Bar charts alone fail to provide a suitable project model because the relationships between different operation are not indicated: The division of a project into its component tasks can be very general, and the bars representing the tasks can be freely overlapped in terms of time [1]. In 1956 Morgan Walker at the Du Pont Company, joined forces with James E. Kelly and used Univac Computer to schedule construction projects [1,11]. This technique acquired a numbers of names, including network

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analysis, critical path analysis, critical path scheduling, and least-cost estimating and scheduling; but the designation Critical Path Method (CPM) is the most satisfactory because there is no limitation implied in its use [3]. The critical path defines the longest path(s) through some network activities (critical activities), from the beginning of the project to its completion. The term critical is used to imply that certain activities (critical activities) have to start and finish at certain times in order for the whole project be completed at the required completion date. The chain connecting critical activities is called the critical path, and the sum of the activity times on the critical path is equal to project duration (before any resource scheduling) [5].

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CPM may be employed not only for the plan and control of construction works, but for research programs, maintenance problems, sales promotion, and related operations in other industries [3]. Today, it is known that CPM does indeed achieve an optimum minimum total cost schedule assuming that the single time estimates are valid and deterministic, and the availability of resources are unlimited [4,5,8]. Using a combination of CPM network schedule and Bar chart (Gantt chart) procedure, resource requirements for a particular schedule can be determined, giving an upper ceiling to the unlimited resources assumed earlier.

The most important advantage of CPM is that management responsible for the project under execution, is compelled to

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plan and think logically from start to finish of a project. Every operation, and the relevant constraints, must appear on the network. Development of such network forces the planner to consult the various departments concerned with the project. Hence, all concerned acquire a fuller understanding of the problems, for it is in this preliminary planning phase that most of the vital decisions are made [4].

2.2 Network Diagram (Activity-On-Arrow:AOA)

The network diagram is an outgrowth of the bar chart (Gantt Chart) which was primarily designed to control the time element of a program. The bar chart can be prepared by specifying the basic approach of scheduling, then breaking the project down into a reasonable number of activities. Activities, represented by a horizontally drawn bars parallel to a horizontal time scale are placed in sequence of their estimated time [9].

Bar charts have not been too successful when projects consisting of large number of activities are being considered, because bar chart does not show explicitly the dependency relationships among the activities. Hence, it is very difficult to account for the effects of delays in individual activities on the project completion. Due to this serious draw back of bar chart, and in the late 1950s, critical path method (CPM) used the arrow diagram technique (Activity-On-Arrow:AOA) for constructing the graphical model for the project network diagram. The analytical procedures which were followed required

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that the network diagram be depicted in terms that could be mathematically expressive to accommodate for the presence of resource(s), permissible early or late scheduling of some activities, and critical activities that need to be scheduled at definite times. Activities, therefore, consume time and their completion is graphically signaled by an event. Events, instantaneous points in time, separate activities, and do not consume time nor resources [4].

The graphical representation of an activity is an arrow. The length, shape, slope, of the arrow has no significance. It may be straight, curved, bent, or wavy to suit the needs of the model. With respect to a given activity, the event number at the head of the arrow is called the "j event" and that at the tail of the arrow is called the "i event". Event numbering ordinarily is not done until the project network has been completed. However, it is a common practice to assign numbers in such a way that the number at the tail of the arrow is smaller than that at the head. A special type of activity is a factious activity that consumes no time and requires no resources. This is called a dummy activity, and is used as an aid in depicting the accurate interrelationships among activities in the Activity-On-Arrow diagram [12], or to maintain a unique numbering.

There are no easy direct approaches to the process of actually drawing the arrow diagram. One method is called "start event approach". The planner begins by putting down the first event

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and the activities that burst from it. Then he/she adds the j events for these activities. For each of these events he/she adds the bursting activities and continues in this manner until the last event is reached. This procedure soon requires correcting the position of the activities when the need for dummies is encountered.

Another method is called "independent activity approach", begins with the planner putting down the activities in an approximate order. Both i and j events are added for each activity. The dependencies are then established by connecting all related events with dummies. The resulting diagram is then reviewed and all unnecessary dummies and events are removed [12].

2.3 Network Calculations: Scheduling of Activity-On-Arrow Network

The time duration for each activity in the network deserves a sound analysis to allow the schedule, which is be subsequently derived using a proper resource allocation procedure, to become an accurate representation of the project. Probably the most direct source for the needed time information is to be found from interviewing the field forces that are actually to perform the work. Also, in most qualified offices which schedule and supervise different industrial and construction projects, records are kept in a manner that allows the planner to determine the required time to accomplish a particular task,

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point in time that any activity bursting form its beginning event (node) can start.

The late finish date of the activity, LFD_{ij}, is the latest point in time that any activity which merges at the activity's ending event can finish. The early finish date, EFD_{ij}, is dependent upon the determination of the early start date. The late start date, LSD_{ij} , is related to the late finish date.

2.3.1 Forward Pass Calculations

The main objective of forward pass computations is to provide the earliest start and finish dates for project activities, and to determine the duration of the project. This time span is found by searching through the network for a continuous chain of activities beginning at the initial event (node), ending at the terminal event, and having the greatest total time duration. This duration comes with the assumption that all resources are unlimited, and must be adjusted after resource allocation schedule is computed. Forward pass calculations begin by assigning certain value for the ESD for all activities that begin at the initial event. Usually, this value is zero. In equation form, the value of EFD_{ij} , for any $activity_{ij}$ of duration T_{ij}, is found using the forward pass as follows:

$$ESD_{ij} = EFD_{ij} - T_{ij} \qquad (2.1)$$

The ESD_{ij} of any $activity_{ij}$ is assigned as the greatest value of EFD of the preceding activities, to ensure that the longest time path is being taken as the project duration [12,13].

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2.3.2 *Backward Pass Calculations*

Backward pass computations provide the latest possible times of occurrence for the start and finish of each activity, extending from terminal event back to initial event of the project network.

The calculations start by assigning a late finish date to all the activities merging at the terminal event in the project and then successively subtracting activity durations along chains of activities until a burst node (event) is reached. At the burst event, the smallest value of late starting dates, calculated for each path leaving that node, is taken as the late finish date for all activities that enter the burst node. The process continues in this manner until the initial node is reached. The equation for the operation is:

$$LSD_{ij} = LFD_{ij} - T_{ij} \qquad (2.2)$$

observe that LFD_{ij} for any $activity_{kj}$ is taken as the minimum of the LSD values of successor activities [11].

2.3.3 *Types of Float (Leeway)*

Total Float = Time span in which the completion of an activity may occur and not delay the termination of the project.

$$TF_{ij} = LFD_{ij} - EFD_{ij} \qquad (2.3)$$

where TF_{ij} is the total float of $activity_{ij}$.

Any $activity_{ij}$, having a $LFD_{ij} = EFD_{ij}$, and $LSD_{ij} = ESD_{ij}$ has a total float equal to zero, and is called a critical activity.

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Free Float: Time span in which the completion of an activity may occur and not delay the finish of the project nor delay the start of any following activity.

$$FF_{ij} = ESD_{jk} - EFD_{ij}$$

where FF_{ij} is the free float of activity$_{ij}$, and ESD_{jk} is the early start date for any following activity$_{jk}$.

Free float is the amount of leeway for an activity if all the activities of the project are to be started at their earliest possible time. As such, it is never greater than, but may be equal to the total float, if the activity ESD_{jk} and LFD_{ij} coincide. This condition is found only when the activity is followed by a critical activity or the j event is an event on the critical path [12,13].

Interfering Float: Time span in which the completion of an activity may occur and not delay the termination of the project, but within which completion will delay the start of some other following activity.

$$INTF_{ij} = TF_{ij} - FF_{ij}$$

where $INTF_{ij}$, is the interfering float of activity$_{ij}$.

2.4 Significance Of The Constrained Resource Problem

Allocation of limited multiresource to different activities (activity requiring different kinds of resources of limited

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it is important to control the cost (direct plus indirect), and the duration of project completion, by utilizing labour, material, equipment, and other scarce resources, in the most effective way possible [5,13].

2.5 Effect Of Constrained Resources On Schedule Floats

After the activities of the project are sequenced in a manner which serves the proposed interrelationships, upon which the fulfillment of the project relies, different float types for each activity are determined using CPM computations. These floats (total and free) are latter used, by different heuristics or any resource allocation procedure, to reschedule some of the project concurrent activities in order to satisfy their demands for the limited resources available.

In general, the following are some of the effects of constrained resources on schedule floats [13]:

1- Resource constraints reduce the total amount of schedule float.

2- The early and late start schedule are typically not unique. Which means that float values are also not unique. These values depend upon the scheduling rules used for resolving resource conflicts.

3- The critical path in a resource-constrained schedule may not be the same continuous chain(s) of activities as occurring in the theoretical unlimited resources schedule.

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A continuous chain of zero total float activities may exist, but since activity start times are constrained by resource availabilities as well as interrelated relationships this chain may contain non-critical activities.

The float developed by constrained resource schedule can be determined, and may be used in any further rescheduling of some of the activities when time-cost trade-off procedures are being used to investigate the most economical project schedule and duration.

2.6 Combinatorial Nature Of Constrained Resource Project Scheduling

The task of scheduling a set of project activities, such that both interrelationships and constraints on resources are satisfied, is not an easy one, even for projects of only modest size [2,5,13]. The difficulty is increased if simultaneously some objective such as minimum project duration or minimum total cost is sought.

This problem stems from the fact that it represents a class of combinatorial problems. This class of problems is characterized by a factorial growth in the amount of computation required to consider all possible solutions as problem size and constraints increase. This is a major reason behind the relatively less practicality of using optimization procedures in scheduling

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such projects, rather than using heuristic methods.

Efficient methods of finding an exact optimal solution to combinatorial problems have not been found [6], as a result, there has been increasing attention given in recent years to the problem of constrained resource scheduling, and most new developments in the field of network procedures have been in this area [1,8,11]. Combinatorial nature of such problems would mean, that for any given project, a very large number of possible combinations of activity start times exist, with each combination representing a different project schedule. The number of combinations is extremely large, even for fairly small problems of 20 to 30 activities, and increases rapidly with an increase in the number of activities. In fact, the number is typically so large for realistic-sized problems as to prohibit enumeration of all alternatives, even with the aid of computer [9,13].

Analytical methods such as mathematical programming have not proven very successful on these combinatorial problems. Amazingly, under appropriate assumptions, some hard combinatorial problems can be solved to a certain optimality by a very simple concept of reappraisal of some fundamental notions of combinatorial complexity. Sometimes, the complexity of a problem may be caused by excessive assumptions on the availability of precise information. This yields yet another frame work for the appreciation of heuristics [8,11].

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2.7 Network Summary Measures (Characteristic Features)

The experience gained in resource-constrained scheduling, with heuristic and optimization procedures, has clearly shown that the effectiveness of both types of procedures is strongly dependent upon the characteristic features of the particular problem being solved [13]. The need for a methodology of describing or measuring the difference between networks has been long studied. In optimization procedures, computational requirements are a valid network summary measure. Another use, in the case of heuristics, would be predicting which of several heuristics might be most effective when scheduling a particular project.

Network characteristic features, usually called summary measures, are divided into three general classes [7]:

1- Measures which characterize the size, shape, and logic (interrelationship structure) of network.

2- Measures which indicate time characteristics.

3- Measures which characterize resource demands and availabilities.

These summary measures can be further distinguished as to whether they are obtained before or after application of any of the standard project scheduling procedures, such as critical path determination [13]. In general, the measures available only to resource-associated problems are subdivided into two categories [8] according to whether they are designed to

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measure:

a- resource requirements of the network, or

b- relationships between resource requirement and availability.

2.8 Behaviour Of Some Selected Heuristics

Edward, W.D., and James, H.P., addressed the problem of scheduling the activities of a project in order to minimize the project duration under the conditions of multi-constrained-resource requirements and availabilities [7]. Eight heuristic scheduling rules were selected to be measured relative to optimum scheduled duration for a group of hypothetical projects.

The experiment consisted of successively solving 83 different hypothetical projects, first with a bounded enumeration procedure, to obtain an optimum scheduled duration, then with each of the selected heuristics. The selection of these heuristics was based upon work and research performed previously.

The hypothetical projects used in the experiment involved 57 different computer-generated networks. These networks were arbitrarily limited in size to between 20 and 27 activities to guarantee ease of obtaining optimum solution.

Within these constraints, individual networks were generated under a procedure which produced projects with such

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characteristic features as network structure and resource requirements, similar to those encountered by the authors in practice. For example, the ratio of number of arcs to number of activities in some hypothetical projects varied between 1.0 and 3.0. Activity durations varied between one and nine time units according to the same frequency distribution of projects tested by Johnson. Each activity had fixed multiple unit requirements of up to 3 different resource types, with a maximum of 3 types per project. All types were subject to fixed resource availabilities which were constant over the project duration. Some of the heuristics used were:

a) Minimum Job Float: Priority in resolving resource conflicts is given to the activity with minimum float.

b) Minimum late finish time: This rule assigns priorities to activities on the basis of activity LFD (as determined by usual CPM). This rule was found effective by Pasco, Mueller-Mehrabch, and Gonguet [6,7]..

c) Shortest Imminent Operation: This "shortest job first" rule assigns priority on the basis of activity duration.

The conclusion drawn was that non of the heuristics tested performed consistently best on all 83 problems. Which means that little about the behaviour of such heuristics is known. The authors concluded that the ambiguous nature of the relationship between the heuristic and the project network is the reason behind such undesirable results.

Pascoe, T.L., attempted to answer the question of whether

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results based on relatively small problems can be extended to larger ones. He concluded that the most effective heuristics for smaller problems were also most effective for larger problems [7].

2.9 Summary

Project scheduling in the presence of limited resources is a challenging problem, even though it may be easy to state and to visualize. Efficient methods of finding an exact optimal solution to the problem have not been successful. This is not surprising since the problem is known to be of a combinatorial nature.

Heuristic procedures have been utilized to get reasonably good solutions in short computation times. Different heuristic rules have been thoroughly examined and tested for their performance. No existing heuristics tested performed consistently best on project scheduling. However, some rules may be more effective in certain types of constrained resource project-scheduling problems. The minimum job float heuristic appeared most effective of those tested in [1,6,7].

Current research on heuristics is focused on analyzing empirically such procedures, that is; the selection of an appropriate set of hypothetical projects (Testnetworks) and the proper statistical analysis of the results. Another area of concern is to find a potential relationship between different

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heuristics and project networks, in order to give a relatively sound bases for determining about which heuristic to use to schedule which project.

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CHAPTER THREE
USE OF HEURISTICS IN SCHEDULING

The research in this thesis follows primarily two parallel tracks. First track looks for heuristics of potential interest and recognition. Second track paves the way for the generation of Testnetworks which depicts some important summary measures developed by previous researches.

3.1 Constrained Resources Affecting Scheduling

Resource constraints, while increasingly important, complicate and alter some of the basic notions of CPM. One difference occurs to the longest sequence of activities through the project, when resource availabilities are constrained. The longest sequence may not be the same critical path determined by the basic time analysis of CPM approach. Another difference, is that, with the basic time analysis procedures, there is one unique Early Start Date (ESD) schedule, while under resource constraints many different ESD schedules may exist [13].

Meeting the schedule is possible if the equipment and manpower, on which the duration estimates are based, are available on time and with sufficient quantities. Concerning the constrained resources which are used in this thesis, the following facts are valid:

1- Availability of constrained resources are certain. No

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uncertain resources are used, and thereafter, no classification of constrained resources, whether rented or owned, are adopted.

2- The need for a constrained resource(s) of each activity is constant. The specified amount of each kind of constrained resources remains fixed throughout activity duration.

3- Resource availability remains constant until there is no further requirement of such resource.

4- Single-constrained resource, and multi-constrained resource situations are investigated.

5- Number of constrained resources constituting the multi-constrained resource problems, is determined by adhering to the objective of this thesis, and allowing for a maximum practical benefit. It is important to keep in mind; the choice of the heuristic is less critical if constraints (including constrained resources) on any project are Severe [1], which undermines the ability of this research to detect any relationship possible between different heuristics and network summary measures.

6- Constrained resources, once used on an activity of a project, cannot be unscheduled and used on another operation instead [1].

A rough measure of resource "tightness" or criticality, computed in preliminary resource allocation planning, is known as criticality index [13].

$$\text{criticality index} = \frac{\text{avg. units req'd of a resource per-period}}{\text{max. amount available of that resource per-period}}$$

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$$C.I. = \frac{r\text{(units of a resource/ time)}}{a\text{(units of a resource/ time)}}$$

where:

$$r = \frac{\text{total cumulative requirements of a resource}}{\text{time span of project duration within which that resource has been scheduled}}$$

a = max., per-period amount available of constrained resource.

Total cumulative requirements of a resource can be determined after the critical path values of the network and associated floats are being developed:

Activities of the network are scheduled either as early as possible or as late as possible, and then bar chart schedule for the network is drawn. From this bar chart, the period by period requirements of each constrained resource is found. The sum of these requirements forms the total cumulative requirements for that constrained resource, over the time span within which that resource has been scheduled.

In general, higher values of the resource criticality index calculated are associated with the most critical (most tightly constrained) resources; values significantly below 1.0 are typically associated with non-constraining resources, while values around and above 1.0 indicate that project delay beyond original critical path duration is highly expected [8,13].

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3.2 Testnetworks Development and Related Summary Measures

Though considered naive because they assume unlimited resource availabilities [1,3,13], the popularity of CPM procedure has proven that network models are a useful means of formulating a wide variety of activity planning and scheduling problems. One of the main advantages of the network model for project planning, is the ease with which information about resource requirements, over the duration of the project, can be generated. The only condition for obtaining this information is that the resource requirements, associated with each project activity shown in the network, be identified separately. Network model, on the other hand, schedules activities of a project in a sequence, if followed, brings the project to completion. If the estimated durations of the activities are not exceeded, and time is not lost in delays, the project finishes on time [1,9,13].

A Testnetwork can depict a real-life project by separating project activities into unique groups of activities. Each group contains number of activities which are related to each other, mostly performed sequentially, and seize some specific resources which are almost exclusive to such tasks and activities. Every group is portrayed as a complete activity in the Testnetwork, with certain duration and resource requirements. This is a practical application of planning methodology which divides a large and complex project network into subprojects or subnetworks [1,6,13].

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One of the major weaknesses of CPM is the fact that activities cannot be intermittent [12]. When a portion of an activity has been scheduled but not the remainder, it can be delayed up to the maximum split delay allowed for this activity. The remaining part of the activity is put in the queue of the next time period for resource allocation. This happens because; it is often more cost effective to stop a specific activity for a certain period of time, thus allowing its resources to be used in another way, which saves both time and money. But due to the highly dependent nature of the research upon CPM, and less interest is given to cost analysis (taken care of by time/ cost trade-off procedures), splitting of activities is not considered.

Many projects have activities of both kinds; those for which time estimates can be accurately made, and those that are highly uncertain [1]. In Testnetworks developed, activities durations are deterministic, because uncertainly could establish another criterion for scheduling activities.

An obvious possible limitation to the extension of Testnetworks developed, is the size and complexity of problems encountered in practice. Practical projects often contain hundreds or thousands of activities and involve numerous resource types per activity. Thus, a natural question is whether results based on relatively small problems can be extended to such practical cases!

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projects, limited and unlimited resources are required. Resource allocation procedures are used to schedule such projects under constrained-resource availability. It is impossible to schedule constrained resources using any valid constrained-resource scheduling procedure, which assumes fixed amount of resources, and at the same time, schedule unlimited resources using resource leveling procedures which assumes fixed project duration. Therefore, the maximum amount of unlimited resources are determined by time/ cost trade-off procedures, giving the feasible economical schedule of the project.

The manner of distinguishing between limited and unlimited resources, allows, at this stage of constrained resource scheduling, to develop practical Testnetworks of relatively small amount of multi-constrained resources, and thereby, facilitate the choice of heuristics which is affected by severity of the amount of constrained resources. Thus, even though we have relatively small amount of multi-constrained resources, Testnetwork can depict a real-life problem by considering other resources to be unlimited, and are dealt with at the next stage of scheduling (time/ cost trade-off scheduling). Therefore, if a project requires five different types of resources, it is expected only to have at most three types of limited resources, and the others are considered unlimited.

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Testnetworks carry certain summary measures which could conceivably be used as the basis for categorizing the types of project networks encountered in practice in certain industries [8]. Table (3.1) shows some of these summary measures [13].

Table 3.1: Network Summary Measures

No.	Summary Measures Describtion
I.	Measures that characterize network size, shape, and logic Examples: Length: max. no. of consecutive nodes from beginning to end. Width: max. no. of nodes in parallel. Rank-Associated Network Measures Complexity: $\frac{\text{No. of arcs}}{\text{No. of nodes}}$.
II.	Measures that indicate time characteristics of the network Examples: Sum of Activity Duration. Variance in Activity Duration. Critical Path Duration. Total Network Float. Density: $\frac{\text{Sum of activity durations}}{\text{Sum of durations + total free float}}$
III.	Measures that characterize resource demands/availabilities Examples: Total Work Content (equivalent to cumulative resource requirements). Average Resource Requirement Per Activity. Average Resource Requirement Per Period. Criticality Index (a measure of resource tightness in terms of requirement versus availabilities).

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A measure of network logic, has been given the name complexity by Pascoe [8,13]. It is the ratio of number of arcs to number of nodes. As the number of arcs increases, the complexity value increases which indicates an increase in "interconnectedness" of the network.

Prior to the usual critical path analysis, sum of activity duration, average activity duration, and variance in activity duration, are three measures which indicate time characteristics of the network.

After critical path analysis is performed, network density, suggested by Pasoe is determined. For this measure, $0 < \text{Density} \leq 1.0$. Used in resource scheduling, it can be seen that high values of Density indicates less free float and, consequently, less freedom to make sequencing decisions without causing further resource conflict. In a network with Density = 1.0, all activities are critical [8].

Criticality Index (C.I.) has been discussed earlier in section 3.1. If more than one constrained resource is present in a network, summary measure, related to resource demands/ availabilities, describing such a network, is set to be equal to the greatest value of each summary measure obtained for each constrained resource.

Another kind of measures is called "Rank-Associated Network Measures". Klovstad [8] utilized the concept of activity rank.

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Essentially, the rank of an activity is based on the maximum number of predecessor activities along a path from that activity to the single beginning activity of the project, without regard to activity durations. Utilizing this concept, the activities of a given project network can be ranked and rearranged according to rank order. This arrangement gives a rough indication of network length (the highest computed rank value plus one), and width (maximum number of activities associated with any given rank, measured over all ranks).

Testnetworks are structured to serve the proposed objective of this thesis of finding any potential relationship between different heuristics and network summary measures. Therefore, the number of Testnetworks is to be determined in light of the following two remarks:

1- Testnetworks have to be structured in a manner which depicts all network summary measures mentioned earlier.
2- Each Testnetwork has to be scheduled using CPM and all heuristic procedures under investigation.

3.3 Heuristic Procedures

When resources are strictly limited, the situation can arise where chains that are noncritical must exceed their total float while waiting for their special resources to become available, thus delaying the entire project [4]. Because of the relative lack of success with optimization procedures, heuristics are used to schedule such projects of limited resources [7].

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Great effort, in addressing the problem of developing heuristic procedures which produce "good" feasible solutions, has been expended. By their very nature, heuristic sequencing rules produce solutions with varying degrees of "goodness" depending on the problem undergoing scheduling. It has become a well-known fact concerning use of heuristics; rules that perform well on one problem may perform poor on another, and vice-versa [13].

Kelly [6,7], in one of the earliest papers published on this topic, stated that there was little prior basis for making a choice among different procedures, and that the best test of the "goodness" of a particular approach was if it produced "reasonable" schedules for actual projects. On the other hand, Verhines [6,7], proposed the general use of "minimum late-finish time" priority rule as an effective procedure, on the basis of its ability to produce shorter schedules than other rules.

Whether based on reasonable schedule or shorter schedule of a project, the implementation of heuristics has been considerably advanced by the development of software that allows for a user-friendly interface [11]. Therefore, a "best" result can be obtained by trial and error procedure; employing different heuristics for the same project network, and choosing the best schedule. There is no limit to the number of trials that can be made to optimize the schedule. However, usually less than six trials can generate a near-optimum solution [1]. Nevertheless,

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the design of any heuristic algorithm has to take into consideration the three main concerns: logic, simplicity of application, and computer orientation [5].

Comparative studies, with the objective of minimization of project duration, tested performance of either temporal-related heuristics or resource-related heuristics. Temporal-related heuristics include minimum activity float, minimum late finish time, and shortest activity first. Resource related heuristics include greatest resource utilization, greatest resource demand, and greatest remaining resource demand [5,6]. Those heuristics are among the most popular and widely used procedures in scheduling under constrained resource availabilities.

Many researches have been carried out to test the performance of each, previously mentioned heuristic on several criteria: project delay, resource idle time, and computer processing time. Patterson [6] gave a conclusion of his research, indicating that temporal-related heuristics produce schedules with low project delays at the cost of an inefficient utilization of resources, and resource-related heuristics schedule resources efficiently at the expense of large delays in project durations. It was also shown that minimum float turned out to be most effective by the criterion of total project delay [1,5,6,13]. However, Pascoe [6,7] concluded that the heuristics of late finish time and late start time produced the best results.

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The most recent and complete analysis on the effectiveness of existing heuristics appears in Daveis and Patterson[6,7]. It was found that temporal-related heuristics such as minimum activity float, gave best results.

3.4 Use of Critical Path Values

In order to reach at a conclusion about the behaviour of heuristics in relation to network summary measures, under constrained-resource availability, it is necessary to establish a reference of comparison which indicates the presence of such relationship. The reference is used to measure the delay in project duration, due to the use and behaviour of heuristics in scheduling Testnetworks.

Values obtained from Critical Path Method (CPM) would make a suitable reference of comparison for several reasons:

1- CP values are already necessary to find the required floats which are used in scheduling.

2- The other possible alternative is the use of the optimization procedure. Such techniques are computationally very difficult compared to CPM, and are of a valuable consequences when used to test the effectiveness of different heuristics relative to each other [1,5,6,13], which is not the case of this thesis.

3- It is worth pointing out, that any optimization technique gives project duration according to the number of

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different kinds of constrained resources (single-constrained resources, or multi-constrained resources), while CPM assumes unlimited resources availabilities. Because the number of types of constrained resources is used by different types of summary measures, changing the number of constrained resources affects the reference of comparison if it is an optimal value, or no effect at all if it is a CPM value.

Therefore, to confine the effect of changing the number of types of constrained resources as a valid source of some summary measures, in relation to different heuristics, CPM is used as a reference of comparison.

3.5 Summary

Constrained resources are assumed to be certain in availability, and their need and availability are constant. Situations of single constrained-resource,and multi-constrained resource are considered with the appropriate amount needed to establish different resource-related summary measures.

Testnetworks are truncated from different project networks available in related books and papers used as references of this thesis. Activities in Testnetworks cannot split and their durations are fixed and deterministic. The size of Testnetworks varies to accommodate for different values of size-related

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summary measures. Number of Testnetworks has to take into consideration the data needed to perform such a research.

Critical Path values is used as a reference of comparison in order to investigate the kind of the relationship.

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CHAPTER FOUR
RESEARCH METHODOLOGY

This chapter nominates the heuristics, summary measures, Testnetworks, and computer language, necessary for the attainment of the thesis objective; to develop a relationship between heuristics performance and network summary measures. It also explains the research methodology adopted in this regard.

4.1 Work Plan

In order to achieve the thesis objective, the following work plan has been complied with to arrive at a potential existence of a relationship between heuristics and certain summary measures of project network:

1- The selection of several heuristics that have been commonly used in real-life problems, in order to study their behavior and investigate more about their potential features.

2- The use of a computer language (Turbo Basic) in order to program the selected heuristics, and use them with greater speed and efficiency. It was necessary to use the same heuristic many times, hence, it was important to facilitate this work.

3- Generate groups of Testnetworks with different characteristic features to guarantee the presence of different network summary measures. A substantial number of different Testnetworks has been developed to

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accommodate for the possible network summary measures.

4- Each Testnetwork consisted of relatively small number of activities (from 20 to 30 activities), since the most effective heuristics for smaller projects are also most effective for the larger projects [1,7].

5- Using CPM, the duration of each Testnetwork was found. Because CPM gives the non-constrained-resource scheduling, the duration obtained was the theoretical minimum required to accomplish any project [1,6,7,13]. A computer program is used to find such duration.

6- Constrained resources were applied to the Testnetworks. The behavior of each heuristic was tested by assigning different resources to the activities of each Testnetwork. Some Testnetworks contained single-constrained resources, others contained double or triple-constrained resources. The durations of the Testnetworks were expected to increase due to the presence of such resources.

7- Data obtained form steps 5 and 6 were investigated, using suitable statistical procedures, and the results were used in studying behavior and effectiveness of the selected heuristics in relation to network summary measures. Chapter five explains more about the statistical analysis adopted.

4.2 Heuristics Adopted

What is required, in the heuristic approach, is some basic criteria, along with a procedure, by which the resources may be

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allocated efficiently, with respect to the main objective of reducing the delay in project termination. The criteria comprise a set of predetermined priority rules. An example, is to allocate resources to an activity given that it has the earliest start time, or least float, and so on, among other concurrent activities. The combination of this procedure and the priority rules are known as the heuristic approach [1,16].

There are two general methods of applying heuristics in project resource allocation problems [1,6,9,14,16]. The first method uses a serial procedure to construct a feasible schedule by considering as-yet-unscheduled activities, one at a time, according to the priority rule of the heuristic used. A schedule is filled left to right, starting at time zero. At any point in time, the first schedulable activity, encountered on the list of unscheduled activities, is scheduled and the process repeats. The second method is a parallel procedure by which several activities are scheduled at once, according to the priority rule set by the heuristic. Again, a schedule is filled from left to right, starting at time zero. However, at any time, all schedulable subsets of concurrent activities from the list of unscheduled activities are considered; one such subset is chosen for scheduling, and the process repeats.

Studies have shown that serial method is generally inferior to parallel method [6,9], therefore, parallel method is adopted in this thesis. In recent years, development of heuristic procedures has been confined almost exclusively to parallel

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methods [9]. Nonetheless, Comparative studies with the objective of minimization of project duration, divided heuristics into two heuristic classification [6,7]:

1- Temporal heuristics, incorporating some measure of time. They include, minimum total float, minimum late finish time, and shortest task first.
2- Resource related heuristics. They include greatest resource demand, and greatest remaining resource demand.

The previously mentioned heuristics, and other, have been tested in many researches. Some heuristics represent a collection of those which have been found frequently effective in scheduling concurrent activities, while others have generally produced poor results [6,7,9,14,16]. In this thesis, four heuristics were chosen; two rated effectively, and two rated poorly heuristics (refer to table 4.1). Two others, developed by combining two heuristics, were studied with the postulation of enhancing the capabilities of the less effective heuristics.

The six heuristics adopted were programmed using Turbo Basic computer language, in an attempt to be used most effectively and efficiently. When ties occurred among concurrent activities; all activities competing for constrained resources, possess the same priority rule value of the heuristic used, such ties are generally broken by activity number [16]. In Activity-On-Node networks, activities are given numbers,

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Table 4.1: Heuristics used in Constrained-Resource scheduling

Rule	Notation	Priority Rules Evaluated
1- Minimum Total Float	MINSLK	Schedules first those activities with lowest activity total float.
2- Minimum Late Finish Time	LFT	Schedules first those activities with the earliest value of late finish time.
3- Greatest Resource Demand	GRD	Schedules first those activities with greatest resource demand.
4- Shortest Task First	STF	Schedules first those activities with shortest durations.
5- Combination of 1&3	COM1	Schedules first activities with lowest total float, and at ties, it schedules activities with greatest resource demand.
6- Combination of 4&3	COM2	Schedules first activities with shortest duration, and at ties, it schedules activities with greatest resource demand.

Note: The first four priority rules are arranged in descending order of effectiveness [1,7,8,14,16].

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therefore, the activity with greatest number is scheduled. In turbo-basic program Activity-On-Arrow networks were used, and ties were broken by rescheduling the last activity read by the programme, in the subset of the concurrent activities.

4.3 Network Summary Measures

Various summary measures (characteristic features) of project networks have been tested by different researchers in attempts to explain the relationship between problem characteristics and heuristic effectiveness. Many summary measure were introduced to serve the proposed attempts [8,14,16]. As it was mentioned in section 3.2, summary measures are divided into three general classes:

1- Measures characterizing the size, shape, and logic of the network.
2- Measures indicating time characteristics.
3- Others characterizing resource demands and availabilities.

These summary measures are further divided into two groups; whether they are obtained before or after the application of CPM [8,9,14,16].

Many summary measures would quantify the same feature, but in different formulations, and consequently, in different values. Therefore, in this thesis, and to accommodate for all the classes and groups discussed above, ten summary measures were

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$$2-\ \text{T-DENSITY} = \sum_{j=1}^{N} \max. \begin{Bmatrix} 0, (\#\ \text{Predecessor Activities} \\ -\ \#\ \text{of Successor Activities}) \end{Bmatrix}$$

= Total Activity Density

$$\therefore\ \bar{X}\ \text{DENSITY} = \frac{\text{T - DENSITY}}{N}$$

= Average Activity Density

(time measure computed before CPM)

$$3-\ \text{COMPLEXITY} = \frac{N}{\text{NEVT}} = \text{Project Complexity}$$

(shape measure computed before CPM)

$$4-\ \text{PDENSITY-T} = \frac{\sum_{j=1}^{N} d_j}{\sum_{j=1}^{N} d_j + \sum_{j=1}^{N} TF_j}$$

= Project Density - Total Float

(time measure Computed after CPM)

$$5-\ \text{PDENSITY-F} = \frac{\sum_{j=1}^{N} d_j}{\sum_{j=1}^{N} d_j + \sum_{j=1}^{N} FF_j}$$

= Project Density - Free Float

(time measure computed after CPM)

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selected from several others, each defining a certain value of the characteristic feature of the project network avoiding any unnecessary repetition [8,9,14,16]. The values of the ten summary measures serve as independent variables in a regression model to predict the response of heuristics performance. These values were supplied via the same software used to solve for the different heuristics.

4.3.1 Summary Measures Formulation

Table (4.2): Variables used in Summary Measures

Notation	Description
N	The set of all activities to be scheduled.
R	The set of all resource types.
d_j	Duration of activity j.
r_{jk}	The requirement of resource type k. by activity j.
R_k	Resource ceiling of resource type k.
CP	Critical path duration of the project.
TF_j	Total float of activity j.
FF_j	Free float of activity j.
NEVT	Number of events (nodes) in a project.
$DEMAND_k$	The requirement of resource type k by subset of concurrent activities.

1- $\bar{X}\ DUR = \dfrac{\sum_{j=1}^{N} d_j}{N}$ = Average Activity Duration

(time measure computed before CPM)

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$$2-\ \text{T-DENSITY} = \sum_{j=1}^{N} \max. \left\{ \begin{array}{l} 0, (\#\ \text{Predecessor Activities} \\ -\ \#\ \text{of Successor Activities}) \end{array} \right\}$$

= Total Activity Density

$$\therefore\ \bar{X}\ \text{DENSITY} = \frac{\text{T - DENSITY}}{N}$$

= Average Activity Density

(time measure computed before CPM)

$$3-\ \text{COMPLEXITY} = \frac{N}{\text{NEVT}} = \text{Project Complexity}$$

(shape measure computed before CPM)

$$4-\ \text{PDENSITY-T} = \frac{\sum_{j=1}^{N} d_j}{\sum_{j=1}^{N} d_j + \sum_{j=1}^{N} TF_j}$$

= Project Density - Total Float

(time measure Computed after CPM)

$$5-\ \text{PDENSITY-F} = \frac{\sum_{j=1}^{N} d_j}{\sum_{j=1}^{N} d_j + \sum_{j=1}^{N} FF_j}$$

= Project Density - Free Float

(time measure computed after CPM)

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$$8- \quad TCON_k = \frac{\sum_{j=1}^{N} r_{jk} \cdot d_j}{\left[\sum_{j=1}^{N} \begin{Bmatrix} 1 \text{ if } r_{jk} > 0 \\ 0 \text{ if } r_{jk} = 0 \end{Bmatrix} \right] \cdot \left[R_k \cdot CP \right]} \quad \text{for all } K \in R$$

= Resource Constrainedness Over Time

$$\therefore \bar{X} \text{ CON-TM} = \frac{\sum_{k=1}^{R} TCON_k}{R}$$

= Average Resource Constrainedness Over Time

(resource measure computed after CPM)

$$9- \quad NOVER_k = \sum_{T=1}^{CP} \begin{Bmatrix} 1 \text{ if Demand } k > R_k \\ 0 \text{ if Demand } k \leq R_k \end{Bmatrix} \quad \text{for all } K \in R$$

= Number of Time Periods The demand for Resource K exceeds the availability of Resource K (where the demand is based on all early start schedule)

$$\therefore \bar{X}OVER = \frac{\sum_{k=1}^{R} NOVER_k}{R}$$

= Average Excess Demand Time Period for Resources

(resource measure computed after CPM)

$$10- \quad W_k = \sum_{j=1}^{N} d_j . r_{jk} \quad \text{for all } K \in R$$

= Total Work Content for Resource K.

$$O_k = \sum_{T=1}^{CP} \text{max.} \left\{ 0, \left(\text{Demand}_k - R_k \right) \right\} \quad \text{for all } K \in R$$

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= Excess Resource Requirement K

$$\therefore \text{O-Factor} = \sum_{K=1}^{R} O_k$$

= Obstruction Factor

(resource measure computed after CPM)

The ten summary measures described above, included one shape measure, four time measures, and five resource measures [8,14,16]. Due to the elusive nature of network summary measures, discussed by Haggett and Ghorley in their geography studies [8]:

Mathematical definitions fail to do justice to human intuitive notions of what constitutes shape, only one shape measure is used in the thesis.

4.4 Testnetwork Generation

Testnetworks were generated to serve the proposed research of the thesis, by truncating them from problems (projects) existing in the literature of references used [6]. Problems, artificially generated (not real - life problems), must enable different heuristics to effectively discriminate among activities undergoing scheduling by sustaining appropriate number of activities, constrained resources (resource ceiling and amount required by different activities, of each type utilized), and related summary measures. By the same token, the number of such Testnetworks were of a major consequence upon the responses obtained from the regression model used to

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explain any potential relationship between heuristics and summary measures.

In light of the previous experiments conducted to study the relative effectiveness of different heuristics [6,7,8,9,16], sample networks consisted of activities between 15 and 30 for each network, and demanded constrained resources between 1 to 3 types of such resources, and the number of networks, in each experiment, varied between 50 and 200. Form a statistical point of view, any regression model requires the use of t-test (for a one-regressor-variable model) and /or f-test to find confidence interval prediction interval. In an F-distribution, any sample population, of size $n \geq 120$ (constituting the degrees of freedom) and at a certain $(1-\alpha)*100\%$ level of significance, has an f_{α} value fixed no matter what the value of n is. In T-distribution, the critical range of n is $n \geq 30$ [19].

Thus, the number of Testnetworks tackled in the thesis is 135 networks to accommodate for the D.O.F = n-k-1; where k=10. Also, the number of activities used for each network ranges between 20 and 30, and the number of types of constrained resources ranges from 1 to 3 (refer to 3.1 and 3.2) [1,7,9,14].

4.5 A Turbo-Basic Programme of CPM, Heuristics, and Related Summary Measures

4.5.1 Introduction To Turbo Basic

The original version of BASIC (Beginner's All-purpose Symbolic

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Instruction Code) was developed at Dartmouth College in 1964 as a teaching language. In subsequent years, BASIC underwent many revisions and enhancement [15].

Basic is the most popular computer language in the world. For example, a recent survey by the Boston Computer Society revealed that more than 80% of its programmer members use BASIC ("Developers Pick BASIC for High Productivity," Info World, June 15, 1987). About 500,000 high school and college students enroll in BASIC courses each year [15].

The last 20 years have witnessed the arrival of many fine programming languages. Languages like Pascal and C have control structures that permit beautifully designed and easily maintained programs. Unfortunately, these control structures are missing from most of the BASIC versions that have appeared since the language was invented at Dartmouth College in 1964. Turbo Basic provides the best of both worlds. It is easy to learn and use, and yet has the essential control structures and power of languages like Pascal and C [15].

Turbo Basic is referred to as a compiled language. What is a compiler? The Turbo Basic compiler is a subprogram within Turbo Basic. It reads and understands the instructions of a BASIC program, checks them for certain types of errors, and translates them into machine language. The compiler only needs to read and translate each instruction once - thereby making a compiler much more efficient than an interpreter. The compiler

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does not carry out the instructions that it translates, but does produce a set of machine-language instructions that the computer can execute directly and quickly to accomplish the task of the BASIC program. Two of the outstanding features of Turbo Basic are the speed and the efficiency with which it compiles programs [15].

Turbo Basic has been used to design a software capable of fulfilling efficiently and accurately the different requirements of the thesis. The software incorporates all necessary information about project under scheduling. It performs CPM procedure, allocates constrained resources using any of the six proposed heuristics, and completes all calculations needed for summary measures, and related responses. All data computed can be displayed in relevant tableaux provided by the software.

CPM programme, as an essential part of the software designed, has been prepared by Eng. Suhair Al-Khateb and Eng. Hamadan Awad. Both are students enrolled in the Master's Programme, at the Industrial Engineering Department, Faculty of Engineering and Technology, in the University of Jordan.

4.5.2 Software Structure and Design

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 have today made possible the production of machines of such memory

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capacity and speed that under many conditions of use memory space limitations, and computing time, place little constraint on the programmer. The current emphasis is on structure and style of programming [15].

The generous effort required to design and develop computer software is implicitly recognized by the proportion of time devoted to this task in the training that many specialist people receive.

Every machine requires software to drive it, and for large and difficult jobs or tasks there is probably no real alternative to the purchase of commercial software. Commercial software is likely to suffer from several limitations, from the stand point of view of the purchaser:

1- It is expensive. This is reflected in relative increase of the cost of software compared to the cost of hardware.
2- Not generally amenable to modification by the user, and the input and output are predetermined.
3- The software, to sustain wider marketability, is often far more powerful and consequently complex than the user requirement.

In light of the thesis objective, the writer developed his own software capable of fulfilling his requirement, by understanding the main aspects and limitations of resource allocation.

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Resource allocation, which constitutes the corner stone of the research, starts by locating the activities of the network in terms of their early start and finish dates. At certain points in time, the summation of the requirement for every resource type seized (for equipment), consumed (for materials), or utilized (for manpower) is found. These points in time occur at irregular time intervals, when the value of the summations changes for any resource type.

When the requirement of every type of resource exceeds the maximum availability, for concurrent activities, resource allocation procedure resorts to the priority rule stated by the heuristic algorithm adopted.

According to the heuristic priority rule an activity or more is chosen to be delayed by a certain period of time in order to reduce the amount of resource requirement. The procedure repeats for all the different time intervals of the project, until no further scheduling is needed.

It is highly expected that due to rescheduling of activities, the project duration increases. The delay in project termination form CPM schedule is affected by the heuristic used. Consequently, to detect the inherent relationship between the priority rule of the heuristic, and the delay caused by the presence of constrained resources, it is necessary to adopt several heuristics of which their priority rule is known to the designer of the software. In the same manner, the software must

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be designed to accommodate for the different network summary measures which depict different characteristic features of the project network.

Therefore, it is important to postulate a potential trend of data extracted by the scheduling of numerous number of Testnetworks observed against their respective summary measures. Afterward, a curve is fitted to follow the pattern of data points, which could describe such potential relationship. One approach to follow is multiple linear regression; where the delay is taken to be the response or the dependent variable, and the summary measures of every network are considered the independent variables of the regression model.

A software, called ReALL-1 (Resource ALLocation version-1), was structured and programmed by the writer of the thesis to smoothly facilitate the fulfillment of the resource allocation methodology explained above. The software performs CPM scheduling, resource allocation scheduling, using any of the heuristics investigated, and calculates the summary measures of every Testnetwork. The software is capable of saving all the information concerning every Testnetwork for any future retrieval. Three tableaux can be displayed and/or printed for a hard copy printout. The first tableau depicts CPM schedule, the second tableau shows resource allocation schedule, and the third tableau gives the Testnetworks summary measures. Also, the day-by-day usage of resources by concurrent activities can be displayed on the computer screen.

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The software, is menu driven, and user-friendly programme. At the first stage, the programme asks for the information regarding the project: project name, supervisor name, number of activities, ceiling of constrained resource 1 and/or 2 and/or 3, and for every activity it asks for: Activity name, value of i node, value of j node, duration, resource demand for type 1 and/or 2 and/or 3 resource. This information is stored in different dimensional arrays: A$,L$,N,U1,U2,U3,N$(I), A(I,1), A(I,2), A(I,3), A(I,10), A(I,11), A(I,12); I = 1 To N, respectively. The i value < j value for all the activities, otherwise a warning sound is heard, and a chance is given to retry.

In the second stage, the software computes within few seconds the CPM schedule: early start and finish dates, late start and finish dates, total float, and free floats. The information is stored in a dimensional array: A(I,4), (A(I,5), A(I,6), A(I,7), and A(I,8),A(I,9), respectively.

In order to keep track of both CPM and resource allocation solutions, during the same run of the software, and for any future retrieval of information, all the information stored in A(I,J); J=1 TO 12 is copied into another dimensional array B(I,J); I = 1 To N, J= 1 To 12. This copy is delivered to the third stage.

In the third stage, few seconds pass (depending upon the complexity of the project in terms of dependency relationship,

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resource constrainedness, and number of types of resources used before the software prepares the resource-allocation schedule. The following points are the important aspects of this stage of the software (refer to figures 4.1, 4.2):

1- There are seven different mechanisms working simultaneously to arrive at the heuristically solved resource-allocation schedule:

(a) To find the day-by-day summation of every resource type used in the project mechanism. The summation is compared with the maximum available resources at a certain point in time. If demand ≤ availability, then the software moves forward one unit in time and the process repeats otherwise, it goes to the next mechanism.

(b) To choose, according to the heuristic priority rule, the activity to be delayed amongst the subset of concurrent activities, at the time specified in a. The activity number to be delayed is stored in variable P; P = I.

(c) The third mechanism keeps track of the dependency relationship connecting project activities together.

(d) Here, the software updates the early start and finish dates of the delayed activity, and schedule the remaining activities from the subset. Also, the summation of resource demands are updated by deducing from them the requirement for resources of the delayed activity.

(e) The software shifts all activities connected to and succeed the delayed activity, by updating their relevant early start and finish dates.

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(f) The sixth mechanism of the software checks on the remaining summation of resource demands, at the specified time, and compare them with the available resources. Either another activity is chosen to be delayed, and then the process repeats, or the software advances one unit in time; the process of finding the new summation of resource demands repeats, and a new comparison is studied. The whole process terminates when the time scale adjusted by the software is equal to the maximum early finish time of the project activities, when all activities have been scheduled.

(g) The final important mechanism defines the two time scales along which the software proceed scheduling. The first time scale detects the location of the project activities. This time scale is used to find the maximum early finish time of the terminal activities(T') (refer to figure 4.2). The second time scale is a time counter (T) by which the day-by-day checking on resource demand summation is performed by the software. When all the activities have been scheduled, and when the value of T' coincides with the value of T, the heuristic procedure terminates.

2- It is important to realize that the information about constrained resource project schedule obtained by the software (ReALL-1), is stored in the dimensional array B(I,J); I = 1 To N, and J = 1 To 12. The software, when asked to resolve the project by another heuristic, copies the dimensional array A(I,J), once again into B(I,J).

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Therefore, it is important, if necessary, for the user to allow the software to produce the summary measures tableau, the associated tableau of the heuristic schedule, and the day-by-day summation of resources usage, before going to the next heuristic procedure. Because the summary measures tableau contains a block to depict amount of delay in project termination form CPM, this tableau is only available after the heuristic solution, although summary measures are not affected by heuristic scheduling.

3- At last but no means least, it is vital to draw the attention of the user to the fact that the software, when asked to solve for different heuristic, for the project undergoing scheduling, the only self adjustment the program undertakes is the call for the appropriate subroutine designed to fulfill the requirement of the heuristic. Each heuristic is programmed in a special subroutine (six subroutines for six heuristics). Which means that the seven mechanisms explained earlier are never altered except for mechanism number b.

4.5.3 Using the Software (ReALL-1)

The software is menu driven, and user-friendly programme (see fig 4.1). When the software is run, the following menu appears, with a selection being made:

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```
                    **** MAIN MENU ****


          CHOOSE A NUMBER FROM THE FOLLOWING:

      1- ENTER NEW PROBLEM

      2- READ AN EXISTING PROBLEM

      3- EXIT TO SYSTEM OR DOS

? 2

ENTER EXISTING FILE NAME

? SAILOR
```

The following screen appears:

```
CEILING OF RESOURCE -1 = 0

CEILING OF RESOURCE -2 = 2

CEILING OF RESOURCE -3 = 2
```

ACT. NO.	ACTIVITY NAME	I	J	TIME	DEMAND FOR R1	DEMAND FOR R2	DEMAND FOR R3
1	A	1	2	3	0	2	2
2	B	1	3	7	0	1	2
3	C	2	3	4	0	2	0

```
IS THE INPUT ACTIVITIES CORRECT? (Y/N)

? Y
```

If the answer is N, the following menu appears:

```
ENTER NUMBER OF WRONG ACTIVITIES =
```

Then it asks the user:

```
ENTER ACTIVITY NUMBER =
```

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AND

FOR ACTIVITY NUMBER: (in this example 1,2,or 3)

CHOOSE ONE OF THE FOLLOWING:

1- STARTING NODE INPUT IS INCORRECT.

2- ENDING NODE INPUT IS INCORRECT.

3- DURATION IS INCORRECT.

4- R1-VALUE IS INCORRECT.

5- R2-VALUE IS INCORRECT.

6- R3-VALUE IS INCORRECT.

7- ALL OF THE ABOVE.

8- TO CHANGE PROJECT AND/OR SUPERVISOR NAME.

9- TO CHANGE RESOURCE CEILING R1 AND/OR R2 AND/OR R3.

10- NEXT MENU.

The following menu appears after any correction is made, or if the network was approved without any corrections:

CHOOSE ONE OF THE FOLLOWING:

1- SAVE THE PROBLEM

2- SOLVE THE PROBLEM BY CPM

3- RETURN TO MAIN MENU

If the choice was to solve the problem:

PROJECT NAME: HOME

SUPERVISOR NAME: RJ

I	J	TIME DURATION	ES	EF	LS	LF	TF	FF
1	2	3	0	3	0	3	0	0
1	3	7	0	7	0	7	0	0

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```
1    3         4         3     7     3     7      0      0

THE COMPLETION TIME OF THE PROJECT = 7

1    ---  2         ACTIVITY IS CRITICAL
2    ---  3         ACTIVITY IS CRITICAL
2    ---  3         ACTIVITY IS CRITICAL

                              PRESS ENTER TO CONTINUE
```

If the choice was to save the network, the programme asks:

```
ENTER NEW FILE NAME
```

Afterwards, the following menu appears:

```
              CHOOSE ONE OF THE FOLLOWING:

        1- DISPLAY CPM-SOLUTION ON SCREEN

        2- PRINT CPM-SOLUTION

        3- RETURN TO PREVIOUS MENU

        4- SOLVE PROBLEM BY HEURISTIC PROCEDURE

        5- RETURN TO MAIN MENU
```

If the choice is number 4, the following screen appears (See Fig. 4-2).

```
     CHOOSE ONE OF THE FOLLOWING HEURISTIC PROCEDURES

        1- MIN. TOTAL FLOAT HEURISTIC - MINSLK

        2- GREATEST RESOURCE DEMAND HEURISTIC - GRD

        3- SHORTEST TASK FIRST - STF

        4- 1st HEURISTIC & 2nd HEURISTIC COMBINED

        5- 3rd HEURISTIC & 2ND HEURISTIC COMBINED

        6- EARLIEST LATE FINISH TIME - LFT

        7- GO TO PREVIOUS MENU
```

When any of the heuristic is chosen, the programme starts computing the data required, and the following menu appears after few seconds:

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```
HEURISTIC SOLUTION HAS BEEN EXECUTED

CHOOSE A NUMBER FROM THE FOLLOWING
     1- CALCULATE & DISPLAY SUMMARY MEASURES
     2- DISPLAY HEURISTIC SOLUTION
     3- PRINT SUMMARY MEASURES
     4- PRINT HEURISTIC SOLUTION
     5- RETURN TO PREVIOUS MENU
```

If the choice is number 1 the following tableau appears:

```
PROJ. NAME:HOME        MAX. AVA. R1= 0        CPM TIME= 7
NUM. OF ACT.'S= 3      MAX. AVA. R2= 2        HEU. TIME= 14
NUM. OF EVT.'S= 3      MAX. AVA. R3= 2        DELAY = 7
HEURISTIC #: 3
RETRIEVED FILE NAME: SAILOR
------------------------------------------------------------
X-DEN.=   .33                 X-DUR.=   4.66
DEN.TF=   1                   X-CN-T=   .60
DEN.FF=   1                   X-CON.=   .91
O-FACT=   .63                 X-OVER=   5
X-UTIL=   1.46                COMPLEX=  1
------------------------------------------------------------
1-MINSLK  2-GRD   3-STF   4-COM.  1&2  5-COM.   3&2  6-LFT
     PRESS ENTER TO RETURN TO PREVIOUS MENU
?
```

Or, if the choice is number 2, the following menu appears:

```
A HEURISTIC-PROCEDURE TABLE          HEU.#:3
PROJECT NAME:          HOME
SUPERVISOR NAME:       RJ
RESOURCE CEILING-1:  0
RESOURCE CEILING-2:  2
RESOURCE CEILING-3:  2
```

ACT NO.	ACTIVITY NAME	I	J	TIME	DEMAND FOR R1	DEMAND FOR R2	DEMAND FOR R3	ACT START	ACT END
1	A	1	2	3	0	2	2	0	3
2	B	1	3	7	0	1	2	7	14
3	C	2	3	4	0	2	0	3	7

PRESS ENTER TO GO TO PREVIOUS MENU?

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From the main menu, if the choice was to enter a new problem the following questions appear:

```
ENTER PROJECT NAME
ENTER SUPERVISOR NAME
ENTER NUMBER OF ACTIVITIES
CEILING OF RESOURCE - 1
CEILING OF RESOURCE - 2
CEILING OF RESOURCE - 3
```

And for each activity:

```
NUMBER OF STARTING NODE
NUMBER OF ENDING NODE
ACTIVITY DURATION
DEMAND FOR R1
DEMAND FOR R2
DEMAND FOR R3
```

The user can display the day - by - day summation of usage of resources:

```
CEILING OF RES.-1= 6                                   CPM TIME= 29
CEILING OF RES.-2= 0                                   HEU TIME= 30
CEILING OF RES.-3= 0                                   HEU No. = 2
TIME         USAGE OF            USAGE OF             USAGE OF
             RES.-1              RES.-2               RES.-3
--------------------------------------------------------------------
 0             5                   0                    0
 1             5                   0                    0
 2             5                   0                    0
 3             6                   0                    0
 4             6                   0                    0
 5             6                   0                    0
 6             5                   0                    0
 7             6                   0                    0
 8             6                   0                    0
 9             3                   0                    0
--------------------------------------------------------------------
  1- MINSLK  2-GRD  3-STF  4-COM1&2  5-COM3&2  6-LFT
                 PRESS ENTER TO CONTINUE
```

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The same procedure continues, except when the user unintentionally gives the number of starting node lesser than or equal to number of ending node; a warning beep is heard, and an option is given to retry.

A very vital aspect of the programme is the ability of the user to make use of the CPM procedure, all the heuristics provided, and related summary measures, by introducing any Testnetwork only once. Also, the user can retrieve any existing file of a network, make different changes in resources, activities, durations, and so on. Then the user can save the newly developed network on a separate file as a different project.

4.5.4 *Checking Validity of the Software*

The literature of the references used provided a plentiful number of networks, and the solution of CPM, and several different heuristics. Many of these networks have been used to check the validity of software built. The testing procedure has been repeated at each time a new heuristic was programmed.

Summary measures have been computed manually and compared with the results obtained via the software. When the writer started to introduce the Testnetworks to the software, he purposefully introduced several print statements at different positions in the programme, with special remarks, to check on the step-by-step solution of the software. For about thirty Testnetworks, he obtained hardcopy printouts, and observed the results. Corrections were made, and the five major aspects of

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the programme were observed:

1- The dependency relationship among activities.

2- The activity chosen to be delayed according to the priority rule of the heuristic.

3- The start and the termination dates of every activity.

4- Summation of every resource type throughout the whole project duration.

5- There must exist a continuous chain of interrelated activities.

4.5.5 Summary

The software is mainly composed of five different components:

1- CPM algorithm.

2- Heuristic algorithm.

3- The associated subroutines of the six different heuristic.

4- The summary measures formulation.

5- Related displaying tableaux, and saving and retrieving files.

The software is written in Turbo-Basic computer language, requiring more than 1200 lines, and more than 80 variables. IT is an executable file, and can be further extended as desired.

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CHAPTER FIVE

BEHAVIOUR OF HEURISTICS IN SCHEDULING

The formulation of mathematical models of many physical systems is a basic first step in the process of evaluating their behaviour. Consequently, empirical functional relationship are often developed to describe the behaviour of a system using experimental data [19].

5.1 The Method of the Least-Squares

In fitting data with an approximating function, there are two basic approaches: interpolation and least-squares regression.

The first approach requires the passage of an assumed function (usually a polynomial) through every data point [19]. Yet, this approach suffers from a serious deficiency: to pass a polynomial through every point requires and nth-order polynomial for n+1 data points, which is too complex and inappropriate for large n values.

Alternatively, we resort to the second approach. Least-squares regression which assumes the passage of a curve (function) which best describes the trend of the given data points, without necessarily passing through every data point. The procedure involves approximating a function such that the sum of the squares of the differences between the approximated curve and the actual given data values is minimum [19].

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Some statistical assumptions that are inherent in the Least-squares procedure is that the y value (dependent variables) for a given values of X (independent variables) must be normally distributed. Hence, any curve computed otherwise results in a larger sum of the residuals (the difference between approximated and actual data values). Therefore, Least-squares regression gives a curve which is unique and the best representing the trend of the given data points.

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5.2 Building the Model of the Relationship Between Heuristics and Summary Measures

A useful translation of the least-squares procedure to the problem of finding a potential relationship between the heuristic procedures, studied in the thesis, and the project characteristic features, was in fitting a multiple linear regression model to describe such a relationship.

The amount of delay in project termination from CPM schedule, was considered to be the dependent variable (y), and the ten summary measures adopted were considered the independent variables (x). The model was formulated as:

$$Y = a_0 + a_1x_1 + a_2x_2 + ... + a_{10}x_{10}$$

The terminology "linear" only refers to the model's coefficients; the a's.

One hundred and thirty five projects were scheduled using 6 different heuristics, and 10 summary measures. It was intended to find a model for each heuristics using those 135 Testnetworks as the given data points.

The best values of the 11 coefficients (a_0, a_1, a_2, ..., a_{10}) were determined by setting up the sum of squares of the residuals, $SSE = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (y_i - a_0 - a_1x_{1i} - ... - a_{10}x_{10i})^2$;

$n = 135$ y_i and x_{ki} were the given data such that $k = 10$ and differentiating with respect to each of unknown

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coefficients, and setting the partial derivatives equal to zero; the following simultaneous linear equations (the x_{ki} variables appearing to the first power) were obtained:

$$na_0 + \sum_{i=1}^{n} x_{1i}a_1 + \cdots\cdots + \sum_{i=1}^{n} x_{10i}a_{10} = \sum_{i=1}^{n} y_i$$

$$\sum_{i=1}^{n} x_{1i}a_0 + \sum_{i=1}^{n} x_{1i}^2 a_1 + \cdots + \sum_{i=1}^{n} x_{1i}x_{10i}a_{10} = \sum_{i=1}^{n} x_{1i}y_i$$

$$\vdots \qquad\qquad \vdots \qquad\qquad \vdots$$

$$\sum_{i=1}^{n} x_{10i}a_0 + \cdots\cdots + \sum_{i=1}^{n} x_{10i}^2 a_{10} = \sum_{i=1}^{n} x_{10i}y_i$$

or as a matrix form:

$$\begin{bmatrix} n & \sum_{i=1}^{n} x_{1i} & \cdots\cdots & \sum_{i=1}^{n} x_{10i} \\ \sum_{i=1}^{n} x_{1i} & & \cdots\cdots & \sum_{i=1}^{n} x_{1i}x_{10i} \\ \vdots & & & \\ \sum_{i=1}^{n} x_{10i} & & \cdots\cdots & \sum_{i=1}^{n} x_{10i}^2 \end{bmatrix} \begin{Bmatrix} a_0 \\ a_1 \\ \vdots \\ a_{10} \end{Bmatrix} \begin{Bmatrix} \sum_{i=1}^{n} y_i \\ \sum_{i=1}^{n} x_{1i}y_i \\ \vdots \\ \sum_{i=1}^{n} x_{10i}y_i \end{Bmatrix}$$

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3- g for the STF heuristic:

$$g = \left\{ \qquad \right\}$$

4- g for the Combination of heuristics 1&2:

$$g = \left\{ \qquad \right\}$$

5- g for the Combination of heuristics 3&2:

$$g = \left\{ \qquad \right\}$$

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6- g for the Combination of LFT heuristic:

$$g = \left\{ \quad \right\}$$

Using the software Quattro, the inverse of the matrix A was found:

$$[A]^{-1} =$$

$$\left[\quad \right]$$

And by using the same software, Quattro, the a- coefficient of every model was found:

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1- a- coefficient of MINSLK:

$$a = \left\{ \quad \right\} = [A]^{-1} * g$$

2- a- coefficient of GRD:

$$a = \left\{ \quad \right\} = [A]^{-1} * g$$

3- a- coefficient of STF:

$$a = \left\{ \quad \right\} = [A]^{-1} * g$$

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4- a- coefficient of combination of heuristic 1&2:

$$a = \left\{ \quad \right\} = [A]^{-1} * g$$

5- a- coefficient of combination of heuristic 3&2:

$$a = \left\{ \quad \right\} = [A]^{-1} * g$$

6- a- coefficient of of LFT:

$$a = \left\{ \quad \right\} = [A]^{-1} * g$$

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Therefore, the multiple linear regression function for each heuristic is:

1- For MINSLK:

$$y = 13.227 + 5.214x_1 - 12.274x_2 + 9.078x_3 + 0.029x_4 + 7.923x_5 + 1.356x_6 + 85.482x_7 + 7.824x_8 + 0.774x_9 - 16.177x_{10}$$

2- For GRD:

$$y = 9.828 + 6.459x_1 - 21.146x_2 + 15.214x_3 + 0.138x_4 + 11.690x_5 + 2.028x_6 + 70.828x_7 + 5.636x_8 + 0.285x_9 - 12.201x_{10}$$

3- For STF:

$$y = 13.023 + 22.387x_1 - 17.724x_2 + 10.223x_3 - 0.155x_4 + 10.25294x_5 + 1.909x_6 + 77.130x_7 + 6.675x_8 + 0.339x_9 - 17.650x_{10}$$

4- For Combination of heuristics 1&2:

$$y = 1.000 + 11.981x_1 - 15.208x_2 + 13.342x_3 - 0.096x_4 + 5.119x_5 + 1.311x_6 + 105.076x_7 + 9.209x_8 + 0.810x_9 - 21.069x_{10}$$

5- For Combination of heuristics 3&2

$$y = 12.808 + 20.032x_1 - 18.994x_2 + 8.467x_3 + 0.098x_4 + 9.705x_5 + 2.051x_6 + 89.732x_7 + 7.141x_8 + 0.339x_9 - 16.184x_{10}$$

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6- For LFT:

$$y = 22.042 + 16.246x_1 - 19.295x_2 + 11.231x_3 - 0.076x_4 + 10.254x_5 + 2.317x_6 + 82.972x_7 + 8.136x_8 + 0.327x_9 - 22.293x_{10}$$

5.3 Properties Of The Least-Squares Estimator

The following sample network was generated to test the properties of the Least-Squares estimators.

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5.3 Properties Of The Least-Squares Estimator

The following sample network was generated to test the properties of the Least-Squares estimators.

PROJECT NAME : PREDICTION
SUPERVISOR NAME : INTERVAL

ACT. NO.	ACTIVITY NAME	I	J	TIME	DEMAND FOR R1	DEMAND FOR R2	DEMAND FOR R3
1	A	1	2	3	2	0	0
2	B	1	3	2	1	0	0
3	C	1	4	1	2	0	0
4	D	2	5	5	1	0	0
5	E	3	6	4	1	0	0
6	F	3	7	2	1	0	0
7	G	4	10	1	1	0	0
8	H	5	9	1	1	0	0
9	I	6	8	3	2	0	0
10	J	7	8	5	2	0	0
11	K	7	10	3	1	0	0
12	L	8	9	4	1	0	0
13	X	8	13	3	1	0	0
14	M	9	14	6	1	0	0
15	N	10	11	2	2	0	0
16	O	10	12	1	2	0	0
17	P	11	15	1	3	0	0
18	Q	12	15	3	1	0	0
19	R	13	15	3	2	0	0
20	S	14	16	3	1	0	0
21	T	15	16	2	2	0	0

Fig. (5.1): a- Sample network used to find confidence and prediction intervals.

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PROJECT NAME : PREDICTION
SUPERVISOR NAME : INTERVAL

I	J	TIME DURATION	ES	EF	LS	LF	TF	FF
1	2	3	0	3	4	7	4	0
1	3	2	0	2	0	2	0	0
1	4	1	0	1	14	15	14	0
2	5	5	3	8	7	12	4	0
3	6	4	2	6	2	6	0	0
3	7	2	2	4	2	4	0	0
4	10	1	1	2	15	16	14	5
5	9	1	8	9	12	13	4	4
6	8	3	6	9	6	9	0	0
7	8	5	4	9	4	9	0	0
7	10	3	4	7	13	16	9	0
8	9	4	9	13	9	13	0	0
8	13	3	9	12	14	17	5	0
9	14	6	13	19	13	19	0	0
10	11	2	7	9	17	19	10	0
10	12	1	7	8	16	17	9	0
11	15	1	9	10	19	20	10	5
12	15	3	8	11	17	20	9	4
13	15	3	12	15	17	20	5	0
14	16	3	19	22	19	22	0	0
15	16	2	15	17	20	22	5	5

THE COMPLETION TIME OF THE PROJECT = 22

THE FOLLOWING ARE CRITICAL ACTIVITIES:
1 - 3
3 - 6
3 - 7
6 - 8
7 - 8
8 - 9
9 - 14
14 - 16

Fig. (5.1): b- CPM schedule of the sample network.

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```
P. N.:PREDICTION        MX.R1= 3            CPM = 22
N.ACT.´s= 21            MX.R2= 5            HEU = 34
N.EVT.´s= 16            MX.R3= 4            DEL = 12
HEU #: 1                SAVING FILE NAME:PREDIN2
--------------------------------------------------------------------
   X-DEN =   .4285714328289032     X-DUR = 2.761904716491699

   DEN.TF=   .7160493731498718     X-CN-T= 4.736652597784996E-002

   DEN.FF=   .3694267570972443     X-CON.= .392857164144516

   O-FACT=   .7779331803321838     X-OVER= 9.666666984558105

   X-UTIL=   .9760100841522217     COMPLX= 1.3125
--------------------------------------------------------------------
1-MINSLK  2-GRD  3-STF  4-COM. 1&2  5-COM. 3&2  6-LFT
```

Fig. (5.1): c- Summary measures of the sample network loaded with three different resource types.

```
P. N.:PREDICTION        MX.R1= 3            CPM = 22
N.ACT.´s= 21            MX.R2= 0            HEU = 31
N.EVT.´s= 16            MX.R3= 0            DEL = 9
HEU #: 1                SAVING FILE NAME:PREDIN
--------------------------------------------------------------------
   X-DEN =   .4285714328289032     X-DUR = 2.761904716491699

   DEN.TF=   .7160493731498718     X-CN-T= 5.772005766630173E-002

   DEN.FF=   .362500011920929      X-CON.= .4920634925365448

   O-FACT=   .3125                 X-OVER= 9

   X-UTIL=   1.212121248245239     COMPLX= 1.3125
--------------------------------------------------------------------
1-MINSLK  2-GRD  3-STF  4-COM. 1&2  5-COM. 3&2  6-LFT
```

Fig. (5.1): d- Summary measures of the sample network loaded with one resource type.

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Table 5.1: Summary of the results of the sample network loaded with three different resource types

No.	HEU. NOTAION	CPM TIME	HEU. TIME	DELAY
1	MINSLK	22	34	12
2	GRD	22	31	9
3	STF	22	37	15
4	COM. 1&2	22	34	12
5	COM. 3&2	22	37	15
6	LFT	22	37	15

Table 5.2: Summary of the results of the sample network loaded with one resource type

No.	HEU. NOTAION	CPM TIME	HEU. TIME	DELAY
1	MINSLK	22	31	9
2	GRD	22	33	11
3	STF	22	34	12
4	COM. 1&2	22	31	9
5	COM. 3&2	22	32	10
6	LFT	22	34	12

5.3.1 MINSLK Heuristic

(a) $$SST = \sum_{i=1}^{135} y_i^2 - \frac{\left(\sum_{i=1}^{135} y_i\right)}{135}$$

$$= 15132.93$$

$$SSR = \sum_{j=0}^{k=10} a_j g_j - \frac{\left(\sum_{i=1}^{135} y_i\right)}{135}$$

$$= 9600.69$$

$$SSE = SST - SSR = 5532.24$$

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$$S^2 = \frac{SSE}{n-k-1} = \frac{5532.24}{135-10-1} = 44.62$$

$$R^2 = \frac{SSR}{SST} = 0.634$$

∴ 63.4 % of the variation in the data points, scheduled by MINSLK, has been explained by the model.

(b) For the project shown in *fig (5.1-C)* where:

$x_1 = .42$, $x_2 = .71$, $x_3 = .36$, $x_4 = .77$, $x_5 = .97$, $x_6 = 2.76$, $x_7 = 0.04$, $x_8 = .39$, $x_9 = 9.66$, and $x_{10} = 1.31$, the confidence interval of the mean delay for the MINSLK heuristic was found as follows:

$\sqrt{X_o' A^{-1} X_o} = 0.2708$; X_o = matrix containing the ten summary measures = $[1, x_1, x_2, \ldots, x_{10}]$

Computed at $\alpha = 0.01 \Rightarrow t_{\alpha/2} = 2.576$,

and $\hat{y}_o$ (the delay obtained form MINSLK model) = 14.01

$\therefore \mu_Y / x_{1o}, x_{2o}, \ldots, x_{10o} =$

$= \hat{y}_o \mp t_{\alpha/2}\, s \sqrt{X_o' A^{-1} X_o}$

$= 14.01 \mp 4.66$ the confidence interval.

For the project shown in fig(5.1-d) where:

$x_1 = .24$, $x_2 = .71$, $x_3 = .36$, $x_4 = .31$, $x_5 = 1.21$, $x_6 = 2.76$, $x_7 = -.05$, $x_8 = .49$, $x_9 = 9$, $x_{10} = 1.31$, the confidence interval of the mean delay of the MINSLK heuristic was found as follows:

at $\alpha = 0.01$ $\therefore t_{\alpha/2} = 2.576$

and $\sqrt{X_o' A^{-1} X_o} = 0.2895$

$$\therefore \mu_Y / x_{1o}, x_{2o}, \ldots, x_{10o} = \hat{y}_o \pm t_{\alpha/2}\, s \sqrt{X_o' A^{-1} X_o}$$

$= 17.1 \pm 5$ units of time

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(c) For the project shown in *fig (5.1-c)*, the prediction interval of the delay using MINSLK was found as follows:

at $\alpha = 0.1 \Rightarrow t_{\alpha/2} = 1.282$

and $y_o = \hat{y}_o \pm t_{\alpha/2}\, S \sqrt{1 + X_o' A^{-1} X_o}$

$= 14.0 \pm 8.9$

while the actual delay found by ReALL-1 = 12 units of time.

For the project shown in *fig (5.1-d)*, the prediction interval of the delay was found as follows:

$y_o = \hat{y}_o \pm t_{\alpha/2}\, S \sqrt{1 + X_o' A^{-1} X_o}$ at $\alpha = 0.1$

$= 17.1 \pm 8.9$

while the actual delay found by ReALL-1 = 9 units of time.

5.3.2 *Remaining Heuristics*

The previous calculation was found for the remaining heuristics, and the following is a summary:-

1- For GRD:

(a) SST = 11613.44

SSR = 7019.857

SSE = 4593.582

$S^2 = 37.045$

$R^2 = 0.604$

(b) Confidence interval of project in *fig. (5.1.c)*:

$\mu_Y / x_{1o}, x_{2o}, \ldots, x_{10o} = 11.9 \pm 4.2$

for *fig. (5.1.d)* :

$\mu_Y / x_{1o}, x_{2o}, \ldots, x_{10o} = 17.1 \pm 5$

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(c) Prediction interval of project in *fig. (5.1.c)* :

$y_o = 12.0 \pm 8.1$

and the actual delay computed by ReALL-1 = 9

And for *fig. (5.1-d)*:

$y_o = 15.8 \pm 8.1$

and the actual delay = 11

2- For STF:

(a) SST = 11783.33

SSR = 7235.42

SSE = 4547.90

$S^2 = 36.68$

$R^2 = 0.614$

(b) Confidence interval of project in *fig. (5.1-c)*:

$\mu_Y / x_{1o}, x_{2o}, \ldots, x_{10o} = 14.6 \pm 4.2$

for *fig. (5.1.d)* :

$\mu_Y / x_{1o}, x_{2o}, \ldots, x_{10o} = 18.2 \pm 4.5$

(c) Prediction interval of project in *fig. (5.1-c)* :

$y_o = 14.6 \pm 8.1$

and the actual delay computed by ReALL-1 = 15

And for *fig. (5.1-d)*:

$y_o = 18.2 \pm 8.1$

and the actual delay = 12

3- For COM. 1&2 heuristic:

(a) SST = 14454.15

SSR = 8908.55

SSE = 5545.60

$S^2 = 44.72$

$R^2 = 0.616$

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(b) Confidence interval of project in *fig. (5.1-c)*:

$\mu_Y / x_{1o}, x_{2o}, \ldots, x_{10o} = 11.9 \pm 4.7$

for *fig. (5.1-d)* :

$\mu_Y / x_{1o}, x_{2o}, \ldots, x_{10o} = 16.3 \pm 5.0$

(c) Prediction interval of project in *fig. (5.1-c)* :

$y_o = 11.9 \pm 8.9$

and the actual delay computed by ReALL-1 = 12

And for *fig. (5.1-d)*:

$y_o = 16.3 \pm 8.9$

and the actual delay = 9

4- For COM. 3&2 heuristic:

(a) SST = 11799.75

SSR = 7189.41

SSE = 4610.34

$s^2 = 37.18$

$R^2 = 0.609$

(b) Confidence interval of project in *fig. (5.1-c)*:

$\mu_Y / x_{1o}, x_{2o}, \ldots, x_{10o} = 14.2 \pm 4.3$

for *fig. (5.1-d)* :

$\mu_Y / x_{1o}, x_{2o}, \ldots, x_{10o} = 18.0 \pm 4.5$

(c) Prediction interval of project in *fig. (5.1-c)* :

$y_o = 14.2 \pm 8.1$

and the actual delay computed by ReALL-1 = 15

And for *fig. (5.1-d)*:

$y_o = 18.0 \pm 8.1$

and the actual delay = 10

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5- For LFT:

(a) SST = 13079.73

SSR = 8056.19

SSE = 5023.54

$S^2 = 40.51$

$R^2 = 0.616$

(b) Confidence interval of project in *fig. (5.1-c)*:

$\mu_Y / x_{1o}, x_{2o}, \ldots, x_{10o} = 16.1 \pm 4.4$

for *fig. (5.1-d)* :

$\mu_Y / x_{1o}, x_{2o}, \ldots, x_{10o} = 19.8 \pm 4.7$

(c) Prediction interval of project in *fig. (5.1-c)* :

$y_o = 16.1 \pm 8.5$

and the actual delay computed by ReALL-1 = 15 units of time.

And for *fig. (5.1-d)*:

$y_o = 19.8 \pm 8.5$

and the actual delay = 12 units of time.

5.4 Stepwise Regression

Using the backward elimination approach of the stepwise regression, it can be decided which most insignificant independent variables could be eliminated. Stepwise regression starts by recognizing which independent variable has the smallest sum of squares of errors (SSR).

(1) The variable x_{10} had the smallest SSR. Therefore, it was tested the possibility of removing it from the MINSLK model. After the elimination of the 11^{th} row and column from matrix

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[A], and the related value of g_{10}, the new coefficient of the model were computed:

$$a_{new} = \begin{Bmatrix} -9.16463 \\ -5.10098 \\ -1.56988 \\ 2.780584 \\ 0.160568 \\ 7.422051 \\ 1.521948 \\ 108.1688 \\ 2.635398 \\ 0.804237 \end{Bmatrix}$$

multiplied by g, the value of

$$\sum_{j=0}^{9} a_j g_j = 31401.66$$

$$S^2_{new} = \frac{SST - SSR_{new}}{n - k - 1} \quad ; \; n = 135, \; k = 9$$

$$SSR_{new} = \sum_{j=0}^{k} a_j g_j - \frac{\left(\sum_{i=1}^{n} y_i\right)^2}{n}$$

$$= 9435.93$$

$$\therefore \; S^2_{new} = \frac{15132.93 - 9435.93}{125}$$

$$= 45.57$$

To decide whether x_{10} can be eliminated, f-statistic has been computed,

$$f = \frac{SSR_{old} - SSR_{new}}{S^2}$$

$$= \frac{9600.69 - 9435.93}{45.57} = 3.615$$

and compared with

$$f_{\alpha=0.05}(1,n-k-1) = f_{\alpha=0.05}(1,125) = 3.84$$

Since $f < f_{\alpha=0.01}(1,124)$, it was decided to eliminate x_{10}.

$$y = -9.164 - 5.100x_1 - 1.569x_2 + 2.781x_3 + 0.160x_4 + 7.422x_5 + 1.522x_6 + 108.169x_7 + 2.635x_8 + 0.804x_9.$$

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(2) After the successful elimination of x_{10}, it was observed from the newly developed a- coefficients in step 1, that x_1 had had the smallest SSR.

Therefore it was tested the possibility of removing x_1:
After further elimination of the 2nd row and column form matrix [A], and the related g_1, the new coefficient of the model were computed:

$$a_{new} = \left\{ \quad \right\}$$

multiplied by g, the value of

$$\sum_{j=0}^{9} a_j g_j = 31383.95; \qquad j \neq 1$$

$SSR_{new} = 9418.22$

$S^2_{new} = 45.35$

$$\therefore f = \frac{SSR_{old} - SSR_{new}}{S^2} = 4.02$$

and compared with

$f_\alpha = 0.05\ (1,n-k-1) = f_{\alpha=0.05}\ (1,126) = 4.02$

Since $f > f_{\alpha=0.05}\ (1,126)$

$\therefore$ Do not remove x_1, and the process terminates.

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5.5 Average-Delay Inferences of Time and Resource-Related Summary Measures.

It was stated earlier (refer to section 3.2 & 4.3.1) that summary measures had been divided into three categories: time-related, shape-related, and resource -related summary measures. Also, due to the elusive nature of shape-related summary measures, only one such measure was used. And, in the previous section, and by using backward elimination, this summary measure (x_{10}) was eliminated due to it's insignificant effect on the models produced. Nonetheless, the relationship between shape-related measure and expected delay has been discussed in section 5.6.

To further analyse the data points obtained in the six heuristics used, and based on the two classes of summary measures: time and resource-related measures, it was necessary to separate the effect of the four time-related summary measures, form the effect of the five resource-related summary measures on the expected delay obtained from each heuristic. And keeping in mind that such measures are calculated before any heuristic scheduling, the following procedure has been followed:

1- For every time-related summary measure (B1,B2,B3, and B6), the lowest value and highest value were located (discarding the extreme and rarely obtained values), and the average value was calculated.

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2- To stimulate the effect of time-related summary measures in relation to the expected delay, any Testnetwork possessing at least two time-related summary measures greater than or equal to the respective average values, obtained in step 1, would be marked. To promote the effect of time-related summary measure(s) that were repeatedly observed, and to discriminate among the four such measures, it was unwise to mark only Testnetworks having all the four summary measures ≥ the four mid-point values.

3- Step 1 & 2 were performed for the five resource-related summary measures (B4,B5,B7,B8,B9).

4- To separate the effect of time-related measures form resource-related measures, it became evident that marked Testnetwork possessing relatively high values of time-related measures, and low values of resource-related measures, could be easily separated form other marked Testnetworks of high values of resource-related measures, and low values of time-related measures, by eliminating the commonly marked Testnetworks appearing in step 2 & 3. Those eliminated and marked Testnetworks possess high values of time and resource-related measures.

5- The number of Testnetworks, obtained for their relatively high values of the time-related measures, were equal 26 marked Testnetworks.

6- The number of Testnetwroks, obtained for their relatively high values of the resource-related measures, were equal to 31 marked Testnetworks.

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Table 5.4 Testnetworks number of the four time-related measures (refer to appendix A-II).

8, 11, 14, 19, 33, 49, 52, 57, 59, 60, 63, 68, 79, 82, 86, 95, 100, 101, 104, 106, 108, 120, 123, 124, 126, 129.

Table 5.5 Testnetworks number of the five resource-related measures (refer to appendix A-II).

2, 5, 12, 13, 15, 21, 29, 43, 46, 47, 50, 56, 61, 77, 78, 81, 82, 85, 96, 99, 103, 105, 111, 115, 116, 118, 120, 122, 128, 130, 132.

According to the Average-Delay Inference results, it was important to decide if there was a significant difference among the performance of the six heuristics, under the isolated effect of the fowr time-related measures from the effect of the five resource-related measures.

The following test of hypotheris was carried out:

$$H_0 = \mu_1 - \mu_2 = d_0 = 0$$

$$H_1 = \mu_1 - \mu_2 \neq = 0$$

The null hypothesis (H_0) states that there is no significant difference (d_0) between the performance of any two heuristics, against the alternative hypothesis (H_1) which states that there is such a difference.

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1- For time-related summary:

The t-statistic is:

$$t^1 = \frac{(\bar{x}_1 - \bar{x}_2) - d_0}{\sqrt{(s_1^2 / n_1) + (s_1^2 / n_1)}} \qquad \text{(t-statistic)}$$

$$\nu = \frac{(s_1^2 / n_1 + s_2^2 / n_2)^2}{\frac{(s_1^2 / n_1)}{n_1 - 1} + \frac{(s_2^2 / n_2)^2}{n_2 - 1}} \qquad \text{(D.O.F)}$$

where:

$n_1 = n_2 = 26$

$d_0 = 0$

$\sigma_1 \neq \sigma_2$ standard deviation of population scheduled by two different heuristics

$\bar{x}_1$ = average delay of 1st heuristic

$\bar{x}_2$ = average delay of 2nd heuristic

s_1= standard deviation of sample undergoing scheduling by 1st heuristic.

s_2= standard deviation of sample undergoing scheduling by 2nd heuristic.

2- For time-related summary measures:

all of the above is valid except for $n_1 = n_2 = 31$.

Table 5.6 shows the results of the test of hypothens

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Table 5.6 Hypothesis testing of $\mu_1 = \mu_2$

Heuristics compared	Time Measures		Resource Measures	
	t	ν	t	ν
1&2	.054	47.37	.183	54.60
1&3	-.073	48.23	.018	57.31
1&4	-.074	49.89	.292	59.39
1&5	-.048	45.12	-.013	57.81
1&6	-1.000	49.88	-1.145	58.73
2&3	-.143	49.89	-1.880	59.35
2&4	.028	48.23	.145	57.23
2&5	-.121	49.50	-.223	59.04
2&6	-1.172	48.27	-1.545	58.20
3&4	.156	48.95	.307	59.18
3&5	.032	48.96	-.035	59.97
3&6	-1.021	48.97	-1.303	59.69
4&5	-.137	46.21	-.337	59.46
4&6	-1.099	50.00	-1.526	59.87
5&6	-1.110	46.25	-1.255	59.85

From the results obtained in table 5.6, and at α = .1 to .2, the null hypothesis ($H_0 = \mu_1 = \mu_2$) was accepted, for both time and resource-related measures. It was concluded that these was no significant difference in the performance of the first five heuristics, and that the performance of the last heuristic (LFT) was the modest.

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5.6 Linear Regression of Shape-Related Summary Measure

The further analysis of the behaviour of shape-related measure relative to the expected dealy obtained from heuristic scheduling, was studied separately from the other measures. Linear regression model was adopted where the dependent variable (y) was the expected delay, and the independent variable was x_{10}.

The following results were obtained:

<u>For the MINSLK heuristic:</u>

$$b = \frac{n \sum_{i=1}^{135} x_{10i} y_i - \left(\sum_{i=1}^{135} x_{10i} \right) \left(\sum_{i=1}^{135} y_i \right)}{n \sum_{i=1}^{135} x_{10i}^2 - \left(\sum_{i=1}^{135} x_{10i} \right)^2}$$

$$= \frac{135 * 2339.012 - 186.65 * 1722}{135 * 259.712 - (186.65)^2}$$

$$= -25.32$$

$$a = \frac{\sum_{i=1}^{135} y_i - b \sum_{i=1}^{135} x_{10i}}{n}$$

$$= \frac{1722 - (-25.32)\ (1.86.65)}{135}$$

$$\therefore\ y = a - bx_{10}$$

$$y = 47.76 - 25.32\ x_{10}$$

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Also,

$$S_{xx} = \sum_{i=1}^{135} x_{101}^2 - \frac{\left(\sum_{i=1}^{135} x_{101}\right)^2}{n}$$

$$= 259.71 - \frac{186.65^2}{135} = 1.65$$

$$S_{yy} = \sum_{i=1}^{135} y_i^2 \quad - \frac{\left(\sum_{i=1}^{135} x_{101}\right)^2}{n} = SST$$

$$= 36781 - \frac{(1722)^2}{135} = 14816$$

$$S_{xy} = \sum_{i=1}^{135} x_{101}^2 y_i - \frac{\left(\sum_{i=1}^{135} x_{101}\right)\left(\sum_{i=1}^{135} y_i\right)}{n}$$

$$= 2339.01 - \frac{186.65 * 1722}{135}$$

$$= -44.81$$

$$\therefore SSR = b\, S_{xy}$$

$$= (-25.32)\ (-41.8)$$

$$= 1058.38$$

$$\therefore SSE = SST - SSR$$

$$= 14816 - 1058.38$$

$$= 1375.62$$

$$s^2 = \frac{SSE}{n-2} = \frac{13757.62}{135-2} = 103.44$$

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The correlation coefficient of the relation between expected delay and shape summary measure (x_{10}) is:

$$r = b \sqrt{\frac{S_{xx}}{S_{yy}}} = -25.32 \cdot \sqrt{\frac{1.65}{14816}}$$

$= -0.27$

$\therefore r^2 * 100\% = 7\%$ of the total variation of the values of the expected delay in the sample was accounted for by a linear relationship with the shape-related summary measure.

(2) For the GRD heuristic:

$b = -14.17$

$a = 32.04$

$\therefore y = 32.04 - 14.17\ x_{10}$

$S_{xx} = 1.65$

$S_{yy} = 11613 = SST$

$S_{xy} = -23.40$

$SSR = 331.58$

$SSE = 11281.42$

and,

$r = -0.17$

$\therefore r^2 * 100\% = 2.9\%$ of the total variation of the values of the expected delay in the sample was accounted for by a linear relationship with the shape-related summary measure.

(3) For STF heuristic:

$b = -15.31$

$a = 34.06$

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$\therefore$ $y = 34.06 - 15.31\ x_{10}$

$S_{xx} = 1.65$

$S_{yy} = 11788 = SST$

SSR = 387.00

SSE = 11400.99

r = 0.18

$\therefore$ $r^2 * 100\% = 3.2\%$ of the total variation of the values of the expected delay in the sample was accounted for by a linear relationship with the shape-related summary measure.

(4) For COM. MINSLk & GRD heuristic:

b = -14.33

a = 32.11

$\therefore$ $y = 32.11 - 14.33\ x_{10}$

$S_{xx} = 1.65$

$S_{yy} = 14258 = SST$

$S_{XY} = -43.04$

SSR = 616.76

SSE = 13641.24

r = - 0.15

$\therefore$ $r^2 * 100\% = 2.4\%$ of the total variation of the values of the expected delay in the sample was accounted for by a linear relationship with the shape-related summary measure.

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(5) For COM. STF & GRD heuristic:

$b = -14.33$

$a = 32.72$

$\therefore y = 32.72 - 14.33\ x_{10}$

$S_{xx} = 1.65$

$S_{yy} = 42038 = SST$

$S_{xy} = -23.65$

$SSR = 338.94$

$SSE = 11461.06$

$r = -\ 0.17$

$\therefore r^2 * 100\% = 2.9\%$ of the total variation of the values of the expected delay in the sample was accounted for by a linear relationship with the shape-related summary measures.

(6) For the LFT heuristic:

$b = -22.56$

$a = 45.90$

$\therefore y = 45.90 - 22.56\ x_{10}$

$S_{xx} = 1.65$

$S_{yy} = 42038 = SST$

$S_{xy} = -37.03$

$SSR = 835.37$

$SSE = 41202.63$

$r = -\ 0.14$

$\therefore r^2 * 100\% = 2.0\%$ of the total variation of the values of the expected delay in the sample was accounted for by a linear relationship with the shape-related summary measure.

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5.7 Summary

It was noticed that the coefficient of multiple determination (R^2) for the six heuristic were of low value, which indicated that not all the summary measures used were appropriate.

It was noticed too, that when projects using three types of resources, were tested by the six models (such as the project depicted in Fig (5.1 - c), the expected delay was closer to the actual delay computed for every heuristic model, which indicated clearly that resource-related summary measures were of significant effect on the value of the delay calculated by the models.

The stepwise regression model confirmed such finding about the significance of resource-related summary measures, when x_{10} (shape-related measure) was eliminated. And to observe the same effect, the correlation coefficient between shape-related summary measure and the expected delay was low, which indicated clearly the little impact of such measure on the model tested in the multiple linear regression.

The linear regression correlating the shape-related summary measure and the expected delay revealed the inversely proportionate relationship connecting both of them.

When the analysis progressed from a different perspective, the effect of all the four time-related summary measures combined,

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were separated from those of the five resource-related measures. The analysis proceeded in knowing more about the effective of the presence of those two types of measures in relation to heuristics used.

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CHAPTER SIX
DISCUSSION, CONCLUSION, AND RECOMMENDATION

6.1 Discussion

Discussion of the thesis outcomes resides in three different domains: numerical methods adopted, Testnetworks and related summary measures, and the develped software (ReALL-1).

6.1.1 Numerical Methods

Matrices and their algebra are vital to modern engineering mathematics. Matrices arise in the analysis of engineering problems whenever the system under study can be described with a set of n linear algebraic equations in K variables. A linear algebraic equation is one in which a variable (X) only appears to the first power in every term of a given equation [19].

Thus, linear equations can be represented as follows:

$$\sum_{j=1}^{k} a_{ij} X_j = b_i; \qquad i = 1, 2, \ldots, n$$

Using the methods of matrix algebra, these equations can be put in a different form:

$$[A]_{nk} \left\{ X \right\}_k = \left\{ B \right\}_n; \quad \begin{array}{l} n = \text{number of rows} \\ k = \text{number of columns} \end{array}$$

The solution we seek is to find values of K unknowns $\left\{ X \right\}_K$, given values for $[A]_{nk}$ and $\left\{ B \right\}_n$.

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A set of equations in which the number of unknowns is less than the number of equations ($K < n$), may occur in problems involving experimental data, as in the case of this thesis.

Therefore, the least-squares procedure has been employed to get a best and unique solution by approximating a function (line) that fits the general trend of the data obtained, without necessarily matching the individual points, by minimizing the discrepancy between data points and the line [19]. The general mathematical expression for the curve where e is the error or the discrepancy, and K = 10, is:

$$y = a_0 + a_1x_1 + a_2x_2 + \ldots + a_kx_k + e$$

One strategy for fitting a best line through the data would be to minimize the sum of the errors for all data:

$$\sum_{i=1}^{n} e_i = \sum_{i=1}^{n} y_i - a_0 - a_1X_{1k} - a_2X_{1k} - \ldots - a_1X_{1k}$$

n = total number of data points

k = total number of variables.

However, this is an inadequate criterion, because any straight line passing through the midpoint of this fitted line results in a minimum value of the equation above.

Another strategy is to minimize the sum of the absolute values of the discrepancies:

$$\sum_{i=1}^{n} \left| e_i \right| = \sum_{i=1}^{n} \left| y_i - a_0 - a_1X_{1k} - a_2X_{1k} - \ldots - a_1X_{1k} \right|$$

but this criteria does not give a unique solution.

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A third strategy is the maximum criterion. In this technique, the line is chosen to minimize the maximum distance that an individual data point falls from the line. This strategy does not suit to fit data points of which several possess a larger error (located far from the fitted line).

A strategy that overcomes the above shortcomings is the least-squares fit:

$$\sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (y_i - a_0 - a_1X_{1k} - \ldots - a_iX_{ik})^2$$

Therefore, any line derived from this strategy is a unique fitted line. If two criteria are met:

1- The spread of points around the line is of a similar magnitude, and
2- The distribution of these points about the line is normal,

then least-squares procedure provides the best line fitted.

Multiple linear regression, which is based upon the least-squares procedure, is used when more than one independent variable is needed (X_{ik}), and is called linear, because the model is linear in the coefficients (a_i). To test for linearity of the independent variable (X_{ik} is of the first order) can be achieved if the research has the capability of obtaining repeated observations on the response for each value of independent variable (X_{ik}). Only then, the error sum of squares can be divided into two parts:

1- Lack of fit which measures the variation brought about by higher-order curves of independent variables,

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2- Pure experimental error due to the variation between the values of y (dependent variable) at certain values of X (independent variable).

In this thesis no repeated observations can be obtained, because the final schedule of a project proposed by any heuristic is a unique solution. In other words, no matter how many times the network is being solved by the same heuristic, the final schedule is always the same. Also, it is highly unlikely for different projects to have the same ten summary measures which characterize different aspects of each project. Still, it is possible to try different combinations of higher order independent variables if it is recommended in any research.

6.1.2 Summary Measures

Summary measures serve as the independent variables of the multiple linear regression model. A wide variety of such measures can be found in related fields of project scheduling and network modeling. Regarding to the results obtained from the six models built, to describe the relationship between heuristic performance and characteristic features of a project, it has been found that the coefficient of multiple determination (R^2) was almost equal to the six heuristics studied. It has also been noticed that different projects when scheduled using the six heuristics, the delay from CPM was the same for such projects, but then the schedules produced for every project, by the heuristics, were totally different.

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In reference to resource availability and usage, it has been noticed that when the demand was tight, in the sense that each activity required an amount of resources almost equal to the available, any addition over the available resources produced no drop in the delay of project termination date, unless the addition was a multiple of the resources required.

It has been possible by using relatively simple statical procedure, to separate the effect of time-related summary measures from those of resource-related measures. This work has facilitated the analysis of the data obtained.

Stepwise reggression procedure could become immensely troublesome if it used to check on every summary measure of each of the six models, when different significant levels (α-values) are known to produce diffenet results. It is form this perspective, average-delay inferences procedure was designed to furter facilitate such analysis.

6.1.3 The Effect Of Using ReALL-1

The software has facilitated efficiently and effectively the study of the potential relationship between heuristics and summary measures. The software produced all necessary tableaux to investigate the outcomes of the 135 Testnetworks examined. Few seconds would have elapsed before any schedule was produced.

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The software accommodates for the manipulation of three types of constrained resources, and up to 38 activities per network, with a minimum hardware requirement of 220 KB memory preserved for one disk drive, and a color monitor, and a printer for a hardcopy output.

The software can be easily adjusted to accommodate for more types of constrained resources and/or activities per network, taking into consideration the disk-drive memory available and/or processing time. Every additional constrained resource requires an alternation of 10 statements located at different positions of the programme. Every additional activity requires the increase of the horizontal dimensional array preserved for the activities by one.

All the related information of the Testnetworks scheduled was introduced to another software, known as Quattro, to establish all the necessary computations required in multiple linear regression. Different results were produced in tabular forms and were easily contained in this thesis.

6.2 CONCLUSION

1- For activities of a project requiring resources equal to the available have produced tight schedules, which decreased the ability of the heuristics to make effective decision in scheduling the project activities with as little delay as possible. In such cases, the criticality

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of relationship with another heuristic.

4- In reference to table 5.3, it was found that the combination of MINSLK and GRD produced the best heuristic in terms of both time and resource-related summary measures. On the other hand, LFT heuristic produced relatively the lowest performing heuristic, and it was also in terms of both time and resource-related summary measures. GRD heuristic was the relatively second best heuristic, time and resource-related measures wise. From time-related summary measures perspective, MINSLK heuristic, combination of STF and GRD heuristic, and STF heuristic, were ranked the third, fourth, and fifth respectively. From resource-related summary measure perspective, STF heuristic, MINSLK heuristic, and combination of STF and GRD heuristic, were ranked the third, fourth, and fifth respectively.

5- It is evident that both heuristics generated by combining two heuristics perfomed even better than the individual heuristics comprising them.

6- In reference to the study of shape-related summary measure and the expected delay, there was no significant difference in the performance of the six heuristics. Correlation coefficient was low, and the linear model describing every heuristic performance contained low amount of the total variation in the data given. The obvious conclusion drawn was that the measure was inversely proportionate to the expected delay.

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7- From a practical point of view, the thesis provides the students of the Industrial Engineering Department at the University of Jordan, a software which can be utilized in launching other different researches.

8- It was noticed when different previously scheduled networks were introduced to ReALL-1, in order to compare the results of different heuristics with the schedules available, that the results were almost equal, but not the same. Other previously solved networks had schedules exactly the same as those produced by ReALL-1. Networks of the first type contained ties (concurrent activities possessing the same priority rule stated in the heuristic used) and different concurrent activities had to be chosen to be scheduled or delayed. In ReALL-1, when ties occur, the last activity, from the subset of as-yet-unscheduled activities, has to be delayed. This criterion is definitely different from the one used to schedule the networks. Therefore, it was clearly noticeable a criterion must be developed in order to accommodate for such ties. Besides the criterion of selecting the last activity read by ReALL-1 to break ties, two combinations of two heuristics were also introduced. Minimum slack was combined, as the first priority rule, with greatest resource demand as the second priority rule. Also, shortest task first was combined, as the first priority rule, with greatest resource demand.

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6.3 Recommendation

1- Different summary measures must be testedand introduced in higher orders of relationship with the heuristic performance.

2- Other different heuristics must be investigated and studied against summary measures.

3- To change the value of the response, or the dependent variable, in order to discriminate among the performance of different heuristics, when the amount of delay for a project remains the same when scheduled by such heuristics.

4- When the same amount of delay from CPM schedule appears for a project scheduled by different heuristics, feasibility test could be launched to study the most practical and/ or economical schedule.

5- Scheduling of a constrained resource project is the second or the intermediate step after CPM. The third step is time/ cost trade-off procedure. Therefore, it is recommended to proceed in this direction.

6- Many assumptions have been observed in this thesis: availability of constrained resources are certain, the need for constrained resource (s) is constant, resource availability remains constant, constrained resources once used on an activity can not be unscheduled, and no splitting of activities. It is recommended to change some of the these assumption.

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A - I : HARDCOPY

PRINTOUT

OF

LISTING

OF

ReALL-1

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IMPORTANT NOTES ON ReALL-1

1- ACTIVITIES DURATIONS MUST BE OF INTEGER VALUES.

2- THE VALUE OF i OF INITIAL NODE (EVENT) MUST BE GREATER THAN ONE.

3- ReALL-1 ACCOMMODATES FOR UP TO 38 ACTIVITIES, AND 3 DIFFERENT TYPES OF CONSTRAINED RESOURCES PER PROJECT UNDERGOING SCHEDULING.

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```
         DIM A(38,12)        :'ACTIVITY - RELATED DIMENSION FOR CPM
         DIM B(38,12)        :'ACTIVITY - RELATED DIMENSION FOR HEURESTICS
         DIM R1(250)         :'TIME - RELATED SUMMATION OF RESOURCE-1
         DIM R2(250)         :'TIME - RELATED SUMMATION OF RESOURCE-2
         DIM R3(250)         :'TIME - RELATED SUMMATION OF RESOURCE-3
         DIM B1(38)          :'DIMENSIONAL ARRAY USED IN HEURISTICS
         DIM N7$(38)         :'PROJECT ACTIVITIES NAMES
         DIM V(38)           :'DIMENSIONAL ARRAY USED FOR RESOURCE SUMMATION
         DIM D(6,4)          :'SUMMARY OF HEURISTIC RESULTS
         DIM K(38)           :'DIMENSIONAL ARRAY USED IN HEURESTICS
1        SCREEN 0
         COLOR 1, 3, 2
         CLS : LOCATE 5, 5
         PRINT TAB(30); " ****  MAIN MENU  **** "
         PRINT : PRINT : PRINT : PRINT :
         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"
         PRINT TAB(15); "3 - EXIT TO SYSTEM"
22000    INPUT L
         IF L = 1 THEN 18000
         IF L = 2 THEN 15000
         IF L = 3 THEN 30000


         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
         PRINT :
         PRINT "CEILING OF RESOURCE-1";             :'<<
         INPUT A1
         U1 = A1
         PRINT :
         PRINT "CEILING OF RESOURCE-2";             :'<<
         INPUT A2
         U2 = A2
         PRINT :
         PRINT "CEILING OF RESOURCE-3";             :'<<
         INPUT A3
         U3 = A3
         IF A1 > 0 THEN 77
         A1 = 1
77       IF A2 > 0 THEN 78
         A2 = 1
78       IF A3 > 0 THEN 79
         A3 = 1
79       PRINT :
         PRINT TAB(5); "PRESS ENTER TO CONTINUE LOADING REQUIRED INFORMATION";
         INPUT X
```

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```
        FOR I = 1 TO N
        CLS
        PRINT :
        PRINT "FOR ACTIVITY NUMBER "; I
        PRINT :
        PRINT "ACTIVITY NAME";
        INPUT N7$(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
8000    PRINT "ACTIVITY DURATION TIME = ";
        INPUT A(I, 3)
        PRINT :
122     PRINT "DEMAND FOR RESOURCE 1:R1";
        INPUT A(I, 10)
        IF A(I,10) >= 0 THEN 333
        PRINT "DEMAND MUST BE BETWEEN 0 & ";U1;" ...RETRY"
        GOTO 122
333     IF A(I, 10) <= U1 THEN 123
        BEEP
        PRINT :
        PRINT "WRONG ENTRY: R1 > CEILING OF RESOURCE-1";U1;"RETRY..."
        PRINT :
        GOTO 122
123     PRINT "DEMAND FOR RESOURCE 2:R2";
        INPUT A(I, 11)
        IF A(I,11) >= 0 THEN 444
        PRINT "DEMAND MUST BE BETWEEN 0 & ";U2;" ...RETRY"
        GOTO 123
444     IF A(I, 11) <= U2 THEN 124
        BEEP
        PRINT "WRONG ENTRY: R2 > CEILING OF RESOURCE-2";U2;"RETRY..."
        PRINT :
        GOTO 123
124     PRINT "DEMAND FOR RESOURCE 3:R3";
        INPUT A(I, 12)
        IF A(I,12) >= 0 THEN 555
        PRINT "DEMAND MUST BE BETWEEN 0 & ";U3;" ...RETRY"
        GOTO 124
555     IF A(I, 12) <= U3 THEN 125
        BEEP
        PRINT "WRONG ENTRY: R3 > CEILING OF RESOURCE-3";U3;"RETRY..."
        PRINT :
        GOTO 124
125     NEXT I
```

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```
2000     SCREEN 0
         COLOR 14, 1
         CLS
         COLOR 14, 1, 0
17000    PRINT : PRINT :
         PRINT "PROJECT NAME : "; A$
         PRINT "SUPERVISOR NAME : "; L$
         PRINT "RESOURCE CEILING-1:"; U1
         PRINT "RESOURCE CEILING-2:"; U2
         PRINT "RESOURCE CEILING-3:"; U3
         PRINT :
         PRINT TAB(5); "ACT."; TAB(10); "ACTIVITY"; TAB(21); "I"; TAB(26); "J";
         PRINT TAB(5); "NO."; TAB(10); "NAME"; TAB(36); "FOR R1"; TAB(43); "FOR
         PRINT :
         PRINT TAB(5); "----"; TAB(10); "--------"; TAB(20); "---"; TAB(25); "--
         PRINT :
         J = 5
         FOR R = 1 TO N
         FOR I = R TO J
         PRINT TAB(5); I; TAB(11); N7$(I); TAB(20); A(I, 1); TAB(25); A(I, 2); T
         IF I = N THEN 35000
         NEXT I
         R = I - 1
         J = R + 5
         PRINT :
         PRINT TAB(55); "PRESS ENTER TO CONTINUE"
         INPUT X
         CLS :
         COLOR 14, 1, 0
         PRINT TAB(5); "ACT."; TAB(11); "ACTIVITY"; TAB(21); "I"; TAB(26); "J";
         PRINT TAB(5); "NO."; TAB(10); "NAME"; TAB(36); "FOR R1"; TAB(43); "FOR
         PRINT :
         PRINT TAB(5); "----"; TAB(10); "--------"; TAB(20); "---"; TAB(25); "--
         PRINT : PRINT :
         NEXT R
35000    PRINT : PRINT :
5927     PRINT "IS THE INPUT ACTIVITIES CORRECT ?(Y/N)"
         INPUT X$
         IF X$ = "Y" THEN 1000
         IF X$ = "y" THEN 1000
         IF X$ = "N" THEN 1410
         IF X$ = "n" THEN 1410
         PRINT "ANSWER IS EITHER Y/N; RETRY"
         GOTO 5927
1410     COLOR 1, 7, 7
         PRINT :
         PRINT TAB(5); "1 - TO CHANGE PROJECT AND/OR SUPERVISOR NAME.
         PRINT TAB(5); "2 - TO CHANGE RESOURCE CEILING R1 AND/OR R2 AND/OR R3.
         PRINT TAB(5); "3 - TO CHANGE ACTIVITY-RELATED INFORMATION.
         PRINT TAB(5); "4 - NEXT MENU.
43561    INPUT X
         IF X=1 THEN 2045
         IF X=2 THEN 5005
         IF X=3 THEN 2047
         IF X=4 THEN 1000
         BEEP
         PRINT :
         PRINT "WRONG ENTRY -CHOOSE 1,2,3,OR 4; RETRY"
         GOTO 43561
```

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```
2045    PRINT :
        PRINT "OLD PROJECT NAME:";A$
        PRINT :
        PRINT "NEW PROJECT NAME:"
        INPUT A$
        PRINT :
        PRINT "OLD SUPERVISOR NAME:";L$
        PRINT :
        PRINT "NEW SUPERVISOR NAME:"
        INPUT L$
        GOTO 2000
2047    PRINT :
        PRINT TAB(10);"IF ACTIVITIES ARE WRONG:"
        PRINT :
        PRINT TAB(10);"ENTER NUMBER OF WRONG ACTIVITIES =";
        INPUT T
        PRINT :
        FOR I = 1 TO T
        CLS
        PRINT :
        PRINT "ENTER ACTIVITY NUMBER BETWEEN 1 & ";N
2559    INPUT F
        IF F <= 0 THEN 2554
        IF F <= N THEN 9000
        BEEP
2554    PRINT "ACTIVITY NO. BETWEEN 1 & ";N;"RETRY"
        GOTO 2559
        PRINT :
9000    PRINT "FOR ACTIVITY NUMBER "; F
        PRINT :
        PRINT TAB(10); "CHOOSE ONE OF THE FOLLOWING :"
        PRINT :
        PRINT TAB(15); "1 - IF THE STARTING NODE INPUT IS INCORRECT."
        PRINT TAB(15); "2 - IF THE ENDING NODE INPUT IS INCORRECT."
        PRINT TAB(15); "3 - IF THE DURATION INPUT IS INCORRECT."
        PRINT TAB(15); "4 - IF THE R1-VALUE IS INCORRECT."
        PRINT TAB(15); "5 - IF THE R2-VALUE IS INCORRECT."
        PRINT TAB(15); "6 - IF THE R3-VALUE IS INCORRECT."
        PRINT TAB(15); "7 - CHANGE ACTIVITY NAME."
        PRINT TAB(15); "8 - FOR ALL OF THE ABOVE."
        PRINT TAB(15); "9 - NEXT MENU."
23000   INPUT M
        IF M = 1 THEN 3000
        IF M = 2 THEN 4000
        IF M = 3 THEN 5000
        IF M = 4 THEN 5001
        IF M = 5 THEN 5002
        IF M = 6 THEN 5003
        IF M = 7 THEN 9870
        IF M = 8 THEN 3000
        IF M = 9 THEN 1000
        BEEP
        PRINT : PRINT : PRINT "ENTER CORRECT CHOICE NO. !"
        GOTO 23000
3000    PRINT :
10000   PRINT "NUMBER OF STARTING NODE =";
        INPUT A(F, 1)
        IF M = 8 THEN 11000
        IF A(F, 1) > A(F, 2) THEN 13000
        IF M = 1 THEN 6000
```

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```
4000    PRINT :
11000   PRINT "NUMBER OF ENDING NODE =";
        INPUT A(F, 2)
        IF A(F, 1) >= A(F, 2) THEN 13000
        IF M = 2 THEN 6000
        PRINT :
5000    PRINT "ACTIVITY DURATION TIME =";
        INPUT A(F, 3)
        IF M = 3 THEN 6000
5001    PRINT "CORRECT R1-VALUE =";
        INPUT A(F, 10)
        IF A(F,10) >= 0 THEN 1555
        BEEP
        PRINT "DEMAND MUST BE BETWEEN 0 & ";U1;"...RETRY"
        GOTO 5001
1555    IF A(F, 10) <= U1 THEN 5541
        BEEP
        PRINT "WRONG ENTRY;R1 > CEILING OF RESOURCE-1=";U1;";..RETRY"
        PRINT :
        GOTO 5001
5541    IF M = 4 THEN 6000
5002    PRINT "CORRECT R2-VALUE =";
        INPUT A(F, 11)
        IF A(F,11) >= 0 THEN 666
        BEEP
        PRINT "DEMAND MUST BE BETWEEN 0 & ";U2;"...RETRY"
        GOTO 5002
666     IF A(F, 11) <= U2 THEN 5542
        BEEP
        PRINT "WRONG ENTRY;R2 > CEILING OF RESOURCE-2=";U2;";..RETRY"
        PRINT :
        GOTO 5002
5542    IF M = 5 THEN 6000
5003    PRINT "CORRECT R3-VALUE =";
        INPUT A(F, 12)
        IF A(F,12) >= 0 THEN 777
        BEEP
        PRINT "DEMAND MUST BE BETWEEN 0 & ";U3;"...RETRY"
        GOTO 5003
777     IF A(F, 12) <= U3 THEN 5543
        BEEP
        PRINT "WRONG ENTRY;R3 > CEILING OF RESOURCE-3=";U3;";..RETRY"
        PRINT :
        GOTO 5003
5543    IF M = 6 THEN 6000
9870    PRINT "ENTER NEW ACTIVITY NAME:";
        INPUT N7$(F)
6000    NEXT I
        GOTO 2000
5004    PRINT "OLD PROJECT NAME:"; A$
        PRINT :
        PRINT "NEW PROJECT NAME IS:";
        INPUT A$
        PRINT :
        PRINT "OLD SUPERVISOR NAME:"; L$
        PRINT :
        PRINT "NEW SUPERVISOR NAME IS:"; L$
        GOTO 2000
```

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```
5005    W4=0
        FOR I=1 TO N
        IF A(I,10) < W4 THEN 6547
        W4=A(I,10)
6547    NEXT I
        W5=0
        FOR I=1 TO N
        IF A(I,11) < W5 THEN 6548
        W5=A(I,11)
6548    NEXT I
        W6=0
        FOR I=1 TO N
        IF A(I,12) < W6 THEN 6549
        W6=A(I,12)
6549    NEXT I
        J1 = U1
        J2 = U2
        J3 = U3
82      PRINT :
        PRINT "OLD CEILING OF RESOURCE-1="; J1
        PRINT :
        PRINT "NEW CEILING OF RESOURCE-1=";
        INPUT U1
        IF W4 <= U1 THEN 83
        BEEP
        PRINT "R1 OF AN ACTIVITY > CEILING OF RESOURCE-1;RETRY."
        GOTO 82
83      A1=U1
        PRINT :
        PRINT "OLD CEILING OF RESOURCE-2="; J2
        PRINT :
        PRINT "NEW CEILING OF RESOURCE-2=";
        INPUT U2
        IF W5 <= U2 THEN 84
        BEEP
        PRINT "R2 OF AN ACTIVITY > CEILING OF RESOURCE-2;RETRY."
        GOTO 83
84      A2=U2
        PRINT :
        PRINT "OLD CEILING OF RESOURCE-3="; J3
        PRINT :
        PRINT "NEW CEILING OF RESOURCE-3=";
        INPUT U3
        IF W6 <= U3 THEN 85
        BEEP
        PRINT "R3 OF AN ACTIVITY > CEILING OF RESOURCE-3;RETRY."
        GOTO 84
85      A3=U3
        IF A1 > 0 THEN 771
        A1 = 1
771     IF A2 > 0 THEN 781
        A2 = 1
781     IF A3 > 0 THEN 791
        A3 = 1
791     GOTO 2000
        REM     MENU 1
```

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```
         FOR I = 1 TO N
         IF A(I, 2) <> N1 THEN 60
         IF A(I, 5) < X THEN 60
         X = A(I, 5)
         C = X
60       NEXT I                                        :'<< BACKWARD PASS
         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) = C
         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) = C - A(I, 5)
170      NEXT I
'
'>< >< >< >< >< >< >< >< >< >< >END OF CPM ALGORITHM< >< >< >< >< ><
'
29000    SCREEN 0
         COLOR 1, 3, 7
         CLS : LOCATE 5, 1
         PRINT :
         PRINT TAB(10); "CHOOSE ONE OF THE FOLLOWING :"
         PRINT : PRINT "CPM TIME =";C                          :'<<
         PRINT :
         PRINT "TN=";N$
         PRINT :
         PRINT TAB(15); "1 - DISPLAY CPM-SOLUTION ON SCREEN "
         PRINT TAB(15); "2 - PRINT CPM-SOLUTION "
         PRINT TAB(15); "3 - RETURN TO PREVIEST MENU"
         PRINT TAB(15); "4 - SOLVE PROBLEM BY HEURISTIC PROCEDURE"
         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 1000
         IF L = 4 THEN 427
         IF L = 5 THEN 1
         BEEP
         PRINT "ENTER CORRECT NUMBER; RETRY"
         GOTO 26000
```

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```
'>< >< >< >< >< >< >START OF HEURESTIC ALGORITHM< >< >< >< ><

427     FOR I = 1 TO N             :'<< TO COPY DIMENSIONAL ARRAY A(I,J)
        B(I, 1) = A(I, 1)          :'   ONTO DIMENSIONAL ARRAY B(I,J)
        B(I, 2) = A(I, 2)
        B(I, 3) = A(I, 3)
        B(I, 4) = A(I, 4)
        B(I, 5) = A(I, 5)
        B(I, 6) = A(I, 6)
        B(I, 7) = A(I, 7)
        B(I, 8) = A(I, 8)
        B(I, 9) = A(I, 9)
        B(I, 10) = A(I, 10)
        B(I, 11) = A(I, 11)
        B(I, 12) = A(I, 12)
        NEXT I
        CLS : LOCATE 10, 5
        COLOR 1, 3, 7
        PRINT : PRINT TAB(5);"CHOOSE ONE OF THE FOLLOWING HEURISTIC PROCEDURES:"
        PRINT :
        PRINT TAB(10); "1- MIN. TOTAL FLOAT HEURISTIC - MINSLK"
        PRINT TAB(10); "2- GREATEST RESOURCE DEMAND HEURISTIC - GRD"
        PRINT TAB(10); "3- SHORTEST TASK FIRST - STF"
        PRINT TAB(10); "4- 1st HEURISTIC & 2nd HEURISTIC COMBINED"
        PRINT TAB(10); "5- 3rd HEURISTIC & 2nd HEURISTIC COMBINED"
        PRINT TAB(10); "6- EARLIEST LATE FINISH TIME - LFT"
        PRINT TAB(10); "7- GO TO PREVIOUS MENU"
        PRINT : PRINT :
        PRINT "ENTER THE NUMBER OF SELECTED HEURISTIC"        :'<<<<
69      INPUT H5
        IF H5 < 1 THEN 17
        IF H5 <= 6 THEN 9105
        IF H5=7 THEN 29000
17      BEEP
        PRINT "WRONG ENTRY #;RETRY"
        PRINT :
        GOTO 69
        BEEP
9105    T=0
        PRINT : PRINT : PRINT TAB(5);"FILE UNDER EXECUTION;"
        PRINT TAB(5);"PLEASE WAIT FOR FURTHER INSTRUCTIONS."
575     FOR I=1 TO N
        K(I)=0
        NEXT I
        R1(T) = 0
        R2(T) = 0
        R3(T) = 0
        FOR I=1 TO N
        IF B(I,4) >= A(I,4) THEN  28971
        B(I,4)=A(I,4)
        B(I,5)=A(I,5)
28971   NEXT I
        FOR I = 1 TO N
        IF B(I,3) = 0 THEN 12
        IF B(I, 4) > T THEN 12
        IF B(I, 5) < T + 1 THEN 12
        R1(T) = R1(T) + B(I, 10)                  :'<< RESOURCE SUMMATION
        R2(T) = R2(T) + B(I, 11)
        R3(T) = R3(T) + B(I, 12)
12      NEXT I
```

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```
        IF R1(T) <= A1 THEN 21                     :'<< CHECK RESOURCE DEMAND
        GOTO 909                                   :'   AGAINST AVAILABILITY
21      IF R2(T) <= A2 THEN 22
        GOTO 909
22      IF R3(T) <= A3 THEN 23
        GOTO 909
23      Y6=0
        FOR I=1 TO N
        IF B(I,3) = 0 THEN 697
        IF B(I,5) < Y6 THEN 697
        Y6=B(I,5)
697     NEXT I
        IF T <> Y6 THEN 9097                       :'<< TO EXIT FROM HEURESTIC
        GOTO 28480                                 :'   ALGORITHM
909     IF H5 = 1 THEN GOSUB 611                   :'<< CALLS ON APPROPRIATE
        IF H5 = 2 THEN GOSUB 612                   :'   SUBROUTINE
        IF H5 = 3 THEN GOSUB 613
        IF H5 = 4 THEN GOSUB 614
        IF H5 = 5 THEN GOSUB 615
        IF H5 = 6 THEN GOSUB 616
        FOR I=1 TO N
        IF B(I,4) >= A(I,4) THEN 29172
        B(I,4)=A(I,4)
        B(I,5)=A(I,5)
29172   NEXT I
        FOR I = 1 TO N
        IF I=K(I) THEN 404
        IF I <> P THEN 404                         :'<< P CONTAINS No. OF ACTIVITY
        K(I)=I                                     :'   TO BE SHIFTED; ACTIVITY I=P
        B(I,4) = B(I,4) + 1                        :'   HAS BEEN SHIFTED
        B1(I) = B(I, 2)
        B(I,5) = B(I,4) + B(I,3)
        R1(T) = R1(T) - B(I, 10)
        R2(T) = R2(T) - B(I, 11)
        R3(T) = R3(T) - B(I, 12)
404     NEXT I
        FOR I = 1 TO N
        IF I = P THEN 392
        B1(I) = 0
392     NEXT I
        P=0
        FOR I = 1 TO N                             :'<< SHIFT CONNECTED ACTIVITIES
        IF B1(I) = 0 THEN 110
        F = B1(I)
        FOR J = 1 TO N
        IF B(J,4) <> B(I,5)-1 THEN 25
        IF B(J, 1) <> F THEN 25
        B(J,4) = B(I,5)
        B(J,5) = B(J,4) + B(J,3)
        B1(J) = B(J,2)
25      NEXT J
110     NEXT I
        FOR I=1 TO N
        IF B(I,4) >= A(I,4) THEN 29183
        B(I,4)=A(I,4)
        B(I,5)=A(I,5)
29183   NEXT I
        IF R1(T) <= A1 THEN 7134                   :'<< CHECK ON DEMAND/AVAILABILITY
        GOTO 909
7134    IF R2(T) <= A2 THEN 7135
        GOTO 909
7135    IF R3(T) <= A3 THEN 9097
        GOTO 909
9097    T=T+1                                      :'<< MOVE ONE TIME UNIT
        GOTO 575
```

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```
'>< >< >< >< >END OF HEURESTIC ALGORITHM< >< >< >< >< >< ><

25000   PRINT " PROJECT NAME : "; A$
        PRINT " SUPERVISOR NAME : "; L$
        PRINT :
        PRINT TAB(2); "I"; TAB(8); "J"; TAB(15); "TIME"; TAB(25); "ES"; TAB(35)
        PRINT TAB(13); "DURATION"
        PRINT :
        PRINT TAB(1); "---"; TAB(7); "---"; TAB(12); "----------"; TAB(24); "--
        PRINT :
        J = 10
        FOR R = 1 TO N
        FOR I = R TO J
        PRINT TAB(0); A(I, 1); TAB(7); A(I, 2); TAB(15); A(I, 3); TAB(25); A(I,
        IF I = N THEN 40000
        NEXT I
        R = I - 1
        J = R + 10
        PRINT :
        PRINT TAB(55); "PRESS RETURN TO CONTINUE"
        INPUT X
        CLS :
        COLOR 14, 1, 0
        PRINT :
        PRINT "PROJECT NAME:"; A$
        PRINT :
        PRINT TAB(2); "I"; TAB(8); "J"; TAB(15); "TIME"; TAB(25); "ES"; TAB(35)
        PRINT TAB(13); "DURATION"
        PRINT :
        PRINT TAB(1); "---"; TAB(7); "---"; TAB(12); "----------"; TAB(24); "--
        PRINT :
        NEXT R
40000   PRINT :
        PRINT "THE COMPLETION TIME OF THE PROJECT = "; C
        PRINT :
        PRINT "PRESS ENTER TO READ CRITICAL ACTIVITIES"
        INPUT X
        CLS
        PRINT :
        PRINT "THE FOLLOWING ARE CRITICAL ACTIVITIES:"
        FOR I = 1 TO N
        IF A(I, 8) > 0 THEN 60000
        PRINT TAB(5);A(I, 1);"-";A(I, 2)
60000   NEXT I
        COLOR 7, 1
        PRINT : PRINT TAB(55); "PRESS ENTER 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 :
        IF M = 1 THEN 10000
        IF M = 2 THEN 11000
        GOTO 10000
```

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```
20000   PRINT "IS PRINTER INSTALLED - Y/N"
        INPUT R2$
        IF R2$="Y" THEN 4742
        IF R2$="y" THEN 4742
        IF R2$="N" THEN 29000
        IF R2$="n" THEN 29000
        BEEP
        PRINT :
        PRINT "YOUR CHOICE MUST BE YES (Y) OR NO (NO);RETRY:"
        GOTO 20000
4742    LPRINT : LPRINT " PROJECT NAME : "; A$
        LPRINT " SUPERVISOR NAME : "; L$
        LPRINT :
        LPRINT TAB(2); "I"; TAB(8); "J"; TAB(15); "TIME"; TAB(25); "ES"; TAB(35
        LPRINT TAB(13); "DURATION"
        LPRINT TAB(1); "---"; TAB(7); "---"; TAB(12); "----------"; TAB(24); "-
        LPRINT :
        FOR I = 1 TO N
        LPRINT TAB(0); A(I, 1); TAB(7); A(I, 2); TAB(15); A(I, 3); TAB(25); A(I
        NEXT I
        LPRINT :
        LPRINT "THE COMPLETION TIME OF THE PROJECT = "; C
        LPRINT :
        FOR I = 1 TO N
        IF A(I, 8) > 0 THEN 44
        LPRINT TAB(5); A(I, 1); TAB(10); "---", TAB(15); A(I, 2); TAB(25); "ACT
44      NEXT I
        GOTO 29000
14000   PRINT "ENTER NEW FILE NAME "          :'<< INPUT FILES
        INPUT M$
        OPEN "O", #1, M$
        PRINT #1, N
        PRINT #1, A$
        PRINT #1, L$
        PRINT #1, A1
        PRINT #1, A2
        PRINT #1, A3
        PRINT #1, U1
        PRINT #1, U2
        PRINT #1, U3
        FOR I = 1 TO N
        PRINT #1, N7$(I)
        PRINT #1, A(I, 1)
        PRINT #1, A(I, 2)
        PRINT #1, A(I, 3)
        PRINT #1, A(I, 10)
        PRINT #1, A(I, 11)
        PRINT #1, A(I, 12)
        NEXT I
        CLOSE #1
        PRINT TAB(5);"PROBLEM HAS BEEN SAVED, PRESS ENTER TO CONTINUE"
        INPUT X
        GOTO 1000
```

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```
15000   PRINT "ENTER RETRIEVED FILE NAME "
        INPUT N$
        ON ERROR GOTO 55
        OPEN "I", #1, N$                              :'<< RETRIEVED FILES
        INPUT #1, N
        INPUT #1, A$
        INPUT #1, L$
        INPUT #1, A1
        INPUT #1, A2
        INPUT #1, A3
        INPUT #1, U1
        INPUT #1, U2
        INPUT #1, U3
        FOR I = 1 TO N
        INPUT #1, N7$(I)
        INPUT #1, A(I, 1)
        INPUT #1, A(I, 2)
        INPUT #1, A(I, 3)
        INPUT #1, A(I, 10)
        INPUT #1, A(I, 11)
        INPUT #1, A(I, 12)
        NEXT I
        CLOSE #1
        GOTO 2000
55      PRINT : PRINT : PRINT "FILE NOT FOUND"
        PRINT : PRINT "PRESS ENTER TO CONTINUE"
        INPUT X
        GOTO 1
28480   SCREEN 0
        COLOR 1, 3, 2
        CLS
        PRINT : PRINT : PRINT :
        PRINT TAB(10);"FOR THE  USER TO CHECK  THE  FEASIBILITY  OF"
        PRINT TAB(10);"THE  RESULTS  OBTAINED  BY (ReALL - 1),  THE"
        PRINT TAB(10);"FOLLOWING   SUCCESSIVE   TABLES  DEPICT  THE"
        PRINT TAB(10);"DAY - BY - DAY USAGE OF RESOURCES,  COMPARED"
        PRINT TAB(10);"WITH  THE  MAXIMUM  AVAILABILITY  OF EACH OF"
        PRINT TAB(10);"THE RESOURCES UTILIZED, SEIZED, OR CONSUMED."
        PRINT :
        PRINT TAB(15);"FEASIBILTY TEST OF THE SCHEDULE PRODUCED BY (ReALL-1)?"
        PRINT TAB(30);"(Y/N)"
28455   INPUT X$
        IF X$="N" THEN 29066
        IF X$="n" THEN 29066
        IF X$="Y" THEN 28458
        IF X$="y" THEN 28458
        BEEP
        PRINT "THE ANSWER IS YES (Y) OR NO (N); RETRY"
        GOTO 28455
28458   CLS                          :'<<  DAY-BY-DAY USAGE OF RESOURCES
        FOR T=0 TO Y6-1
        R1(T)=0
        R2(T)=0
        R3(T)=0
        FOR I=1 TO N
        IF B(I,4) > T THEN 28481
        IF B(I,5) < T+1 THEN 28481
        R1(T)=R1(T)+B(I,10)
        R2(T)=R2(T)+B(I,11)
        R3(T)=R3(T)+B(I,12)
28481   NEXT I
        NEXT T
```

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```
        PRINT : PRINT :
        PRINT TAB(10);"CEILING OF RES.-1=";U1;TAB(40);"CPM TIME=";C
        PRINT TAB(10);"CEILING OF RES.-2=";U2;TAB(40);"HEU TIME=";Y6
        PRINT TAB(10);"CEILING OF RES.-3=";U3;TAB(40);"HEU No. =";H5
        PRINT TAB(9);"-------------------------------------------"
        PRINT TAB(10);"TIME";TAB(20);"USAGE OF";TAB(31);"USAGE OF";TAB(41);"USA
        PRINT TAB(21);"RES.-1";TAB(31);"RES.-2";TAB(42);"RES.-3"
        PRINT TAB(9);"-------------------------------------------"
        J=9
        FOR R=0 TO Y6-1
        FOR I=R TO J
        PRINT TAB(11);I;TAB(22);R1(I);TAB(32);R2(I);TAB(42);R3(I)
        IF I=Y6-1 THEN 6692
        NEXT I
        R=I-1
        J=R+10
        PRINT TAB(9);"--------------------------------------------"
        PRINT TAB(10);"1-MINSLK 2-GRD 3-STF 4-COM1&2 5-COM3&2 6-LFT"
        PRINT :
        PRINT TAB(25);"PRESS ENTER TO CONTINUE"
        INPUT X
        CLS
        PRINT : PRINT :
        PRINT TAB(10);"CEILING OF RES.-1=";U1;TAB(40);"CPM TIME=";C
        PRINT TAB(10);"CEILING OF RES.-2=";U2;TAB(40);"HEU TIME=";Y6
        PRINT TAB(10);"CEILING OF RES.-3=";U3;TAB(40);"HEU No. =";H5
        PRINT TAB(9);"-------------------------------------------"
        PRINT TAB(10);"TIME";TAB(20);"USAGE OF";TAB(31);"USAGE OF";TAB(41);"USA
        PRINT TAB(21);"RES.-1";TAB(31);"RES.-2";TAB(42);"RES.-3"
        PRINT TAB(9);"-------------------------------------------"
        NEXT R
6692    PRINT TAB(9);"-------------------------------------------"
        PRINT TAB(10);">> FEASIBILITY TEST IS FINISHED; PRESS ENTER TO CONTINUE
        INPUT X
29066   CLS
        PRINT : PRINT : PRINT TAB(10);"HEURISTIC SOLUTION HAS BEEN EXECUTED"
        PRINT TAB(10);"CHOOSE ONE OF THE FOLLOWING:"
        PRINT :
        PRINT TAB(15);"1- CALCULATE & DISPLAY SUMMARY MEASURES"
        PRINT TAB(15);"2- DISPLAY HEURISTIC SOLUTION"
        PRINT TAB(15);"3- PRINT SUMMARY MEASURES"
        PRINT TAB(15);"4- PRINT HEURISTIC SOLUTION"
        PRINT TAB(15);"5- RETURN TO PREVIOUS MENU"
        PRINT TAB(15);"6- SUMMARY OF HEURESTICS RESULTS"
        PRINT : PRINT :
        PRINT "SELECT THE APPROPRIATE NUMBER"
3159    INPUT W3
        IF W3=1 THEN 5931
        IF W3=2 THEN 5932
        IF W3=3 THEN 5933
        IF W3=4 THEN 5934
        IF W3=5 THEN 29000
        IF W3=6 THEN 49231
        BEEP
        PRINT TAB(10);"WRONG ENTRY; RETRY"
        GOTO 3159
5931    PRINT :
```

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```
'>< >< >< >< >< >< >< >START OF SUMMARY MEASURES CALCULATIONS< ><
'
'    >>>>  T - DENSITY    <<<<<
'
          S1 = 0
          FOR I = 1 TO N
          P = I
          T1 = 0
          T2 = 0
          FOR J = 1 TO N
          IF J = P THEN 1801
          IF A(J, 2) <> A(I, 1) THEN 1802
          T1 = T1 + 1
1802      IF A(J, 1) <> A(I, 2) THEN 1801
          T2 = T2 + 1
1801      NEXT J
          D1 = T1 - T2
          IF D1 >= 0 THEN 1803
          D1 = 0
1803      S1 = S1 + D1
          NEXT I
          S1 = S1 / N: 'Xava. DENSITY
'
' >>>>>> DENSITY - FF , DENSITY - TF   <<<<<<<<
'
          S6 = 0
          S7 = 0
          S8 = 0
          FOR I = 1 TO N
          S6 = S6 + A(I, 3)
          S7 = S7 + A(I, 9)
          S8 = S8 + A(I, 8)
          NEXT I
          M1 = S6 + S7
          M2 = S6 + S8
          M3 = S6 / M1
          M4 = S6 / M2
'
' >>>>> O - FACTOR  , X ava. OVER  <<<<<<<
'
          M5 = 0
          M6 = 0
          M7 = 0
          FOR I = 1 TO N
          M5 = M5 + A(I, 10) * A(I, 3)
          M6 = M6 + A(I, 11) * A(I, 3)
          M7 = M7 + A(I, 12) * A(I, 3)
          NEXT I
          IF M5 <> 0 THEN 8761
          M5 = 1
8761      IF M6 <> 0 THEN 8762
          M6 = 1
8762      IF M7 <> 0 THEN 8763
          M7 = 1
8763      O4 = 0
          D4 = 0
```

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```
          FOR T = 0 TO C - 1
          O1 = 0
          O2 = 0
          O3 = 0
          FOR I = 1 TO N
          IF A(I, 4) > T THEN 1912
          IF A(I, 5) < T + 1 THEN 1912
          O1 = O1 + A(I, 10)
          O2 = O2 + A(I, 11)
          O3 = O3 + A(I, 12)
1912      NEXT I
          D1 = O1 - U1
          D2 = O2 - U2
          D3 = O3 - U3
          IF D1 <= 0 THEN 626
          O4 = O4 + 1
626       IF D2 <= 0 THEN 627
          O4 = O4 + 1
627       IF D3 <= 0 THEN 628
          O4 = O4 + 1
628       IF D1 >= 0 THEN 1011
          D1 = 0
1011      IF D2 >= 0 THEN 1012
          D2 = 0
1012      IF D3 >= 0 THEN 1013
          D3 = 0
1013      D4 = D4 + D1 / M5 + D2 / M6 + D3 / M7
          NEXT T
'
'>>>>> S.M. 5,6,7 <<<<<<
'
          M5 = 0
          M6 = 0
          M7 = 0
          L3 = 0
          IF U1 = 0 THEN 783
          L3 = L3 + 1
783       IF U2 = 0 THEN 784
          L3 = L3 + 1
784       IF U3 = 0 THEN 785
          L3 = L3 + 1
785       FOR I = 1 TO N
          M5 = M5 + A(I, 10) * A(I, 3)
          M6 = M6 + A(I, 11) * A(I, 3)
          M7 = M7 + A(I, 12) * A(I, 3)
          NEXT I
          M5 = M5 / (A1 * C)
          M6 = M6 / (A2 * C)
          M7 = M7 / (A3 * C)
          IF L3 <> 0 THEN 7671
          L3=1
7671      L2 = (M5 + M6 + M7) / L3
'
' >>>>>>S.M. 8,9,10 <<<<<<
'
          L4 = 0
          L5 = 0
          L6 = 0
          FOR I = 1 TO N
          IF A(I, 10) = 0 THEN 511
          L4 = L4 + 1
511       IF A(I, 11) = 0 THEN 512
          L5 = L5 + 1
512       IF A(I, 12) = 0 THEN 513
          L6 = L6 + 1
513       NEXT I
```

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```
'...................
        E1 = 0
        E2 = 0
        E3 = 0
        FOR I = 1 TO N
        E1 = E1 + A(I, 10)
        E2 = E2 + A(I, 11)
        E3 = E3 + A(I, 12)
        NEXT I
        IF L4 <> 0 THEN 401
        L4=1
401     IF L5 <> 0 THEN 402
        L5=1
402     IF L6 <> 0 THEN 403
        L6=1
403     E4=(1/L4)*(E1/A1)+(1/L5)*(E2/A2)+(1/L6)*(E3/A3)
        E5 = E4 / L3
'
'..................
'
        L7 = M5 / L4 + M6 / L5 + M7 / L6
        L8 = L7 / L3
'
'.........VALUE OF X ava OVER
'
        O5 = O4 / L3
'
'...........S.M. 9
'
        N8 = 0
        FOR I= 1 TO N1
        N7=0
        P9=I
        FOR J=1 TO N
        IF A(J, 1) <> P9 THEN 6060
        N7 = N7 + 1
6060    NEXT J
        IF N7 < 1 THEN 6069
        N8 = N8 + 1
6069    NEXT I
        N8 = N8 + 1
        O6 = N / N8
        N9 = 0
        FOR I = 1 TO N
        N9 = N9 + A(I, 3)
        NEXT I
        N9 = N9 / N
        X0 = Y6 - C
'
'>< >< >< >< >< >< >END OF SUMMARY MEASURES CALCULATIONS< ><
'
```

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```
39000   CLS                                       :'<< SUMMARY MEASURES TABLEAU
        COLOR 1, 7, 7
        PRINT :
        PRINT "P. N.:"; A$; TAB(22); "MX. R1="; U1; TAB(42); "CPM ="; C
        PRINT "N.ACT.'s="; N; TAB(22); "MX.R2="; U2; TAB(42); "HEU ="; Y6
        PRINT "N.EVT.'s="; N8; TAB(22); "MX.R3="; U3; TAB(42); "DEL="; X0
        PRINT "HEU #:"; H5;TAB(22);"S.F. NE:"; N$
        PRINT "----------------------------------------------------------------
        PRINT :
        PRINT TAB(5);"X-DEN =";TAB(14); S1; TAB(37); "X-DUR =";N9
        PRINT :
        PRINT TAB(5);"DEN.TF=";TAB(14); M3; TAB(37); "X-CN-T="; L8
        PRINT :
        PRINT TAB(5);"DEN.FF=";TAB(14); M4; TAB(37); "X-CON.="; E5
        PRINT :
        PRINT TAB(5);"O-FACT=";TAB(14); D4; TAB(37); "X-OVER="; O5
        PRINT :
        PRINT TAB(5);"X-UTIL=";TAB(14); L2; TAB(37); "COMPLX="; O6
        PRINT "----------------------------------------------------------------
        PRINT "1-MINSLK  2-GRD  3-STF  4-COM. 1&2  5-COM. 3&2  6-LFT"
        PRINT :
        PRINT "PRESS ENTER TO RETURN TO PREVIOUS MENU AFTER ARRANGING D"
        INPUT X
        I=H5
        D(I,1)=I
        D(I,2)=C
        D(I,3)=Y6
        D(I,4)=X0
        GOTO 29066
49231   CLS
        PRINT : PRINT : PRINT :
        PRINT TAB(10);"SUMMARY OF RESULTS OF HEURESTICS USED"    :'<<<
        PRINT :
        PRINT TAB(10);N$
        PRINT :
        FOR I=1 TO 6
        FOR W=1 TO 4
        PRINT D(I,W);
        NEXT W
        PRINT :
        NEXT I
        PRINT :
        PRINT "PRESS RETURN TO CONTINUE"
        INPUT J
        GOTO 29066
5932    SCREEN 0
        COLOR 14, 1, 0
        CLS
        PRINT :
        PRINT "A HEURISTIC-PROCEDURE TABLE"; TAB(35); "HEU.#:"; H5  :'<<<<<
        PRINT "PROJECT NAME : "; A$
        PRINT "SUPERVISOR NAME : "; L$
        PRINT "RESOURCE CEILING-1:"; U1
        PRINT "RESOURCE CEILING-2:"; U2
        PRINT "RESOURCE CEILING-3:"; U3
        PRINT :
        PRINT TAB(5); "ACT."; TAB(10); "ACTIVITY"; TAB(21); "I"; TAB(26); "J";
        PRINT TAB(5); "NO."; TAB(10); "NAME"; TAB(36); "FOR R1"; TAB(43); "FOR
```

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```
        PRINT :
        PRINT TAB(5); "----"; TAB(10); "--------"; TAB(21); "---"; TAB(26); "--
        PRINT : PRINT :
        J = 5
        FOR R = 1 TO N
        FOR I = R TO J
        PRINT TAB(5); I; TAB(10); N7$(I); TAB(20); B(I, 1); TAB(25); B(I, 2); T
        IF I = N THEN 3520
        NEXT I
        R = I - 1
        J = R + 5
        PRINT : PRINT : PRINT :
        COLOR 7, 1
        PRINT TAB(55); "PRESS ENTER TO CONTINUE"
        INPUT X
        CLS :
        COLOR 14, 1, 0
        PRINT TAB(5); "ACT."; TAB(10); "ACTIVITY"; TAB(21); "I"; TAB(26); "J";
        PRINT TAB(5); "NO."; TAB(10); "NAME"; TAB(36); "FOR R1"; TAB(43); "FOR
        PRINT :
        PRINT TAB(5); "----"; TAB(10); "--------"; TAB(20); "---"; TAB(25); "--
        PRINT : PRINT :
        NEXT R
3520    PRINT : PRINT : PRINT TAB(5); "PRESS ENTER TO GO TO PREVIOUS MENU";
        INPUT X
        GOTO 29066
5933    PRINT "IS PRINTER INSTALLED - Y/N"
        INPUT R2$
        IF R2$="Y" THEN 24742
        IF R2$="y" THEN 24742
        IF R2$="N" THEN 29066
        IF R2$="n" THEN 29066
        BEEP
        PRINT :
        PRINT "YOUR CHOICE MUST BE YES (Y) OR NO (NO);RETRY:"
        GOTO 5933
'
' >>>>>>>>> TO PRINT BY PRINTER <<<<<<<<
'
24742   LPRINT :
        LPRINT "PROJ. NAME:"; A$; TAB(25); "MAX. AVA. R1="; U1; TAB(45); "CPM T
        LPRINT "NUM. OF ACT.'s="; N; TAB(25); "MAX. AVA. R2="; U2; TAB(45); "HE
        LPRINT "NUM. OF EVT.'s="; N8; TAB(25); "MAX. AVA. R3="; U3; TAB(45); "D
        LPRINT "HEURESTIC #:"; H5;TAB(22);"RETRIEVED FILE NAME:"; N$
        LPRINT "------------------------------------------------------------------
        LPRINT :
        LPRINT "X-DEN.=";TAB(9); S1; TAB(32); "X-DUR.="; N9
        LPRINT :
        LPRINT "DEN.TF=";TAB(9); M3; TAB(32); "X-CN-T="; L8
        LPRINT :
        LPRINT "DEN.FF=";TAB(9); M4; TAB(32); "X-CON.="; E5
        LPRINT :
        LPRINT "O-FACT=";TAB(9); D4; TAB(32); "X-OVER="; O5
        LPRINT :
        LPRINT "X-UTIL=";TAB(9); L2; TAB(32); "COMPLX="; O6
        LPRINT "------------------------------------------------------------------
        LPRINT "1-MINSLK  2-GRD  3-STF  4-COM. 1&2  5-COM. 3&2  6-LFT"
        LPRINT :
        LPRINT TAB(5); "PRESS ENTER TO RETURN TO PREVIOUS MENU"
        INPUT X
```

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```
        GOTO 29066
5934    PRINT "IS PRINTER INSTALLED - Y/N"
        INPUT R2$
        IF R2$="Y" THEN 34742
        IF R2$="y" THEN 34742
        IF R2$="N" THEN 29066
        IF R2$="n" THEN 29066
        BEEP
        PRINT :
        PRINT "YOUR CHOICE MUST BE YES (Y) OR NO (NO);RETRY:"
        GOTO 5934
34742   LPRINT : PRINT "A HEURISTIC-PROCEDURE TABLE"; TAB(35); "HEU.#:"; H5
        LPRINT "PROJECT NAME : "; A$
        LPRINT "SUPERVISOR NAME : "; L$
        LPRINT "RESOURCE CEILING-1:"; U1
        LPRINT "RESOURCE CEILING-2:"; U2
        LPRINT "RESOURCE CEILING-3:"; U3
        LPRINT :
        LPRINT TAB(5); "ACT."; TAB(10); "ACTIVITY"; TAB(21); "I"; TAB(26); "J";
        LPRINT TAB(5); "NO."; TAB(10); "NAME"; TAB(36); "FOR R1"; TAB(43); "FOR
        LPRINT :
        LPRINT TAB(5); "----"; TAB(10); "--------"; TAB(21); "---"; TAB(26); "-
        LPRINT : PRINT :
        J = 5
        FOR R = 1 TO N
        FOR I = R TO J
        LPRINT TAB(5); I; TAB(10); N7$(I); TAB(20); B(I, 1); TAB(25); B(I, 2);
        IF I = N THEN 8831
        NEXT I
        R = I - 1
        J = R + 5
        LPRINT : LPRINT : LPRINT :
        COLOR 7, 1
        LPRINT TAB(55); "PRESS ENTER TO CONTINUE"
        INPUT X
        CLS :
        COLOR 14, 1, 0
        LPRINT TAB(5); "ACT."; TAB(10); "ACTIVITY"; TAB(21); "I"; TAB(26); "J";
        LPRINT TAB(5); "NO."; TAB(10); "NAME"; TAB(36); "FOR R1"; TAB(43); "FOR
        LPRINT :
        LPRINT TAB(5); "----"; TAB(10); "--------"; TAB(20); "---"; TAB(25); "-
        LPRINT : LPRINT :
        NEXT R
8831    LPRINT : LPRINT : LPRINT TAB(5); "PRESS ENTER TO GO TO PREVIOUS MENU";
        INPUT X
        GOTO 29066
```

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```
'
'>>>>>>>>>>> HEURESTIC SUBROUTINES <<<<<<<<<<<<
'
'
'    SUBROUTINES 611, 612, 613, 614, 615, 616.
'
'    SUBROUTINE # 611 - MINSLK
'
'ARGUMENTS  : Y-COUNTER, K(I)-FOR HEURESTIC PURPOSES, P-ACTIVITY No. TO DELAY
'
611     Y=0
        FOR I = 1 TO N
        IF I=K(I) THEN 707
        IF B(I,3) = 0 THEN 707
        IF B(I, 4) <> T THEN 707
        IF B(I, 8) < Y THEN 707
        Y = B(I, 8)
        P = I
707     NEXT I
        RETURN
'
'   SUBROUTINE # 612  - GRD
'
612     Y = 999
        FOR I = 1 TO N
        IF I=K(I) THEN 7071
        IF B(I,3) = 0 THEN 7071
        IF B(I, 4) <> T THEN 7071
        V1 = B(I, 10) / A1
        V2 = B(I, 11) / A2
        V3 = B(I, 12) / A3
        V(I)= (V1 + V2 + V3)*B(I,3)
        IF V(I) > Y THEN 7071
        Y = V(I)
        P = I
7071    NEXT I
        RETURN
'
'   SUBROUTINE # 613  - STF
'
613     Y = 0
        FOR I = 1 TO N
        IF I=K(I) THEN 7072
        IF B(I,3) = 0 THEN 7072
        IF B(I, 4) <> T THEN 7072
        IF B(I, 3) < Y THEN 7072
        Y = B(I, 3)
        P = I
7072    NEXT I
        RETURN
```

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```
      .
      .     SUBROUTINE # 614  - COMBINATION OF 1&2
      .
 614        Y = 0
            FOR I = 1 TO N
            IF I=K(I) THEN 7073
            IF B(I,3) = 0 THEN 7073
            IF B(I, 4) <> T THEN 7073
            IF B(I, 8) < Y THEN 7073
            Y = B(I, 8)
            P = I
 7073       NEXT I
            N4 = 999
            FOR I = 1 TO N
            IF I=K(I) THEN 7074
            IF B(I,3) = 0 THEN 7074
            IF B(I, 4) <> T THEN 7074
            IF B(I, 8) <> Y THEN 7074
            V1 = B(I, 10) / A1
            V2 = B(I, 11) / A2
            V3 = B(I, 12) / A3
            V(I) = (V1 + V2 + V3)*B(I,3)
            IF V(I) > N4 THEN 7074
            N4 = V(I)
            P = I
 7074       NEXT I
            RETURN
      .   SUBROUTINE # 615  - COMBINATION OF 3&2
      .
 615        Y = 0
            FOR I = 1 TO N
            IF I=K(I) THEN 7075
            IF B(I,3) = 0 THEN 7075
            IF B(I, 4) <> T THEN 7075
            IF B(I, 3) < Y THEN 7075
            Y = B(I, 3)
            P = I
 7075       NEXT I
            N5 = 999
            FOR I = 1 TO N
            IF I=K(I) THEN 7076
            IF B(I,3) = 0 THEN 7076
            IF B(I, 4) <> T THEN 7076
            IF B(I, 3) <> Y THEN 7076
            V1 = B(I, 10) / A1
            V2 = B(I, 11) / A2
            V3 = B(I, 12) / A3
            V(I) = (V1 + V2 + V3)*B(I,3)
            IF V(I) > N5 THEN 7076
            N5 = V(I)
            P = I
 7076       NEXT I
            RETURN
```

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```
.
.  SUBROUTINE # 616  - LFT
.
616     Q = 999
        FOR I = 1 TO N
        IF I=K(I) THEN 7077
        IF B(I,3) = 0 THEN 7077
        IF B(I, 4) <> T THEN 7077
        IF B(I, 7) > Q THEN 7077
        Q = B(I, 7)
        P = I
7077    NEXT I
        RETURN
```

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A - II : DATA OUTPUT

OF THE 135 TESTNETWORKS

SCHEDULED BY THE 6

HEURISTICS USING

ReALL - 1

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Continue Table A-2.1

No.	DEL.	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
46	16	0.27	0.64	0.54	0.38	0.95	2.45	0.07	0.54	9.5	1.37
47	14	0.36	0.64	0.42	0.47	1	2.59	0.04	0.41	7	1.42
48	0	0.26	0.59	0.4	0.02	0.37	2.6	0.02	0.3	1	1.29
49	7	0.37	0.65	0.55	0.22	0.7	3.11	0.03	0.31	5.5	1.5
50	5	0.4	0.56	0.36	0.47	0.79	2.59	0.05	0.45	6.5	1.57
51	22	0.44	0.73	0.56	0.57	1.16	3.31	0.05	0.37	10.5	1.52
52	16	0.34	0.76	0.58	0.23	0.55	3.26	0.03	0.56	7.5	1.35
53	18	0.31	0.66	0.38	0.3	0.72	3.2	0.03	0.36	8.5	1.38
54	11	0.34	0.69	0.46	0.2	0.63	3.54	0.04	0.3	6.5	1.42
55	10	0.39	0.74	0.6	0.44	0.68	2.69	0.05	0.48	5	1.43
56	12	0.28	0.58	0.51	0.24	0.73	2.8	0.06	0.57	6.5	1.39
57	12	0.37	0.84	0.71	0.27	0.85	3.41	0.04	0.36	7.5	1.33
58	11	0.37	0.82	0.47	0.34	0.74	2.95	0.06	0.5	6.5	1.33
59	11	0.38	0.76	0.59	0.15	0.49	2.9	0.04	0.4	3.5	1.39
60	0	0.47	0.62	0.57	0.13	0.34	2.57	0.02	0.28	1.5	1.5
61	6	0.37	0.38	0.29	0.32	0.6	2.18	0.04	0.42	3.5	1.5
62	7	0.37	0.38	0.29	0.35	0.62	2.18	0.02	0.23	5	1.5
63	3	0.4	0.7	0.66	6.31	0.46	2.59	0.03	0.35	3	1.33
64	21	0.4	0.67	0.34	0.18	0.6	5.68	0.04	0.39	10.5	1.29
65	6	0.4	0.8	0.69	0.49	0.81	1.9	0.06	0.45	6	1.46
66	20	0.29	0.79	0.53	0.53	1.05	2.04	0.06	0.42	7.5	1.28
67	13	0.4	0.75	0.61	0.46	0.96	2.84	0.05	0.42	11.5	1.42
68	5	0.36	0.68	0.65	0.25	0.64	2.81	0.04	0.32	5	1.69
69	13	0.38	0.72	0.61	0.37	0.85	2.66	0.06	0.49	5.5	1.5
70	8	0.29	0.74	0.39	0.3	0.7	2.08	0.04	0.35	3	1.26
71	18	0.36	0.76	0.59	0.98	1.77	1.59	0.13	0.58	6.5	1.37
72	43	0.38	0.87	0.717	1.13	2.56	2.34	0.1	0.65	13	1.44
73	18	0.28	0.84	0.51	0.73	1.39	2.38	0.09	0.53	9	1.23
74	15	0.41	0.7	0.45	0.47	1	2.08	0.05	0.42	7	1.4
75	22	0.43	0.72	0.46	0.66	1.24	2.35	0.07	0.43	7	1.47
76	26	0.28	0.8	0.52	0.65	1.32	3.19	0.09	0.55	10	1.23
77	14	0.25	0.8	0.48	0.68	1.13	2.9	0.1	0.38	7.5	1.17
78	11	0.3	0.63	0.38	0.32	0.68	2.11	0.04	0.49	3.5	1.29
79	16	0.34	0.8	0.62	0.32	0.63	2.34	0.02	0.22	5.5	1.31
80	15	0.38	0.69	0.6	0.4	0.71	3.14	0.03	0.24	5.5	1.39
81	16	0.36	0.65	0.47	0.31	1.22	3.09	0.06	0.48	10	1.37
82	23	0.68	0.64	0.44	0.43	1.6	2.51	0.06	0.48	12	1.56
83	13	0.29	0.68	0.49	0.1	0.53	2.62	0.03	0.34	2.33	1.33
84	6	0.33	0.74	0.47	0.18	0.6	3.5	0.02	0.27	4.66	1.42
85	13	0.27	0.79	0.44	0.27	0.64	9.5	0.03	0.37	13	1.15
86	6	0.23	0.84	0.56	0.22	0.61	2.76	0.02	0.25	3.66	1.2
87	15	0.36	0.64	0.42	0.46	0.84	2.59	0.04	0.35	7.66	1.428
88	7	0.27	0.64	0.54	0.43	0.72	2.45	0.04	0.35	5.66	1.37
89	15	0.37	0.65	0.55	0.44	0.65	3.11	0.03	0.35	5.66	1.37
90	16	0.26	0.59	0.4	0.33	0.64	2.6	0.03	0.32	7	1.5

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Continue Table A-2.1

No.	DEL.	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
91	39	0.44	0.73	0.56	1.39	1.58	3.31	0.07	0.47	8.33	1.29
92	2	0.4	0.56	0.36	0.23	0.46	2.59	0.03	0.36	2	1.57
93	2	0.31	0.66	0.38	0.15	0.61	3.2	0.03	0.37	3	1.38
94	21	0.34	0.76	0.58	0.36	0.67	3.26	0.04	0.6	8.33	1.35
95	0	0.39	0.74	0.6	0	0.5	2.69	0.02	0.23	2	1.43
96	13	0.34	0.69	0.46	0.61	0.94	3.54	0.05	0.34	11.3	1.42
97	29	0.37	0.84	0.71	0.58	1.03	3.41	0.05	0.42	8	1.33
98	0	0.28	0.58	0.51	0	0.39	2.8	0.02	0.26	0	1.39
99	16	0.37	0.82	0.47	1	1.2	2.95	0.07	0.53	9.33	1.33
100	11	0.38	0.76	0.59	0.33	0.54	2.9	0.04	0.36	3.33	1.39
101	0	0.47	0.62	0.57	0.03	0.4	2.57	0.03	0.3	1	1.5
102	4	0.37	0.38	0.29	0.57	0.55	2.18	0.03	0.36	2.66	1.5
103	9	0.37	0.38	0.29	0.54	0.63	2.18	0.04	0.42	3.33	1.5
104	3	0.4	0.71	0.66	0.13	0.49	2.59	0.03	0.41	1	1.33
105	20	0.4	0.67	0.34	0.48	0.68	5.68	0.05	0.4	10.3	1.29
106	3	0.4	0.8	0.69	0.39	0.51	1.9	0.04	0.3	3.66	1.46
107	28	0.29	0.79	0.53	0.89	1.12	2.4	0.07	0.44	7	1.28
108	0	0.4	0.75	0.61	8.11	0.5	2.84	0.03	0.3	2	1.42
109	17	0.36	0.68	0.65	0.61	0.93	2.81	0.05	0.4	7.33	1.69
110	5	0.38	0.72	0.61	0.22	0.67	2.66	0.04	0.41	4	1.5
111	15	0.29	0.74	0.39	0.65	0.89	2.08	0.07	0.51	5	1.26
112	10	0.36	0.76	0.59	1.08	1.32	1.59	0.1	0.46	5.33	1.37
113	18	0.38	0.87	0.71	0.53	1.11	2.34	0.06	0.41	6.33	1.44
114	19	0.28	0.84	0.51	0.83	1.16	2.38	0.07	0.46	8	1.23
115	14	0.41	0.7	0.45	0.52	0.93	2.08	0.06	0.52	5	1.41
116	31	0.43	0.72	0.46	1.3	1.78	2.35	0.09	0.59	11	1.47
117	18	0.28	0.8	0.52	0.78	0.92	3.19	0.06	0.42	6.33	1.23
118	35	0.25	0.8	0.48	1.28	1.35	2.9	0.12	0.47	9	1.17
119	5	0.3	0.63	0.38	0.53	0.56	2.11	0.02	0.29	5.33	1.29
120	5	0.34	0.8	0.62	0.45	0.62	2.3	0.04	0.36	3.33	1.31
121	38	0.38	0.69	0.6	1.28	1.54	3.14	0.07	0.54	13.7	1.39
122	8	0.36	0.65	0.47	0.43	0.66	3.09	0.04	0.38	5.66	1.37
123	6	0.68	0.64	0.44	0.44	0.57	2.51	0.04	0.35	3.33	1.562
124	6	0.23	0.84	0.56	0.15	0.56	2.76	0.02	0.24	2.66	1.2
125	0	0.29	0.68	0.49	0	0.55	2.62	0.02	0.29	0	1.33
126	8	0.34	0.8	0.62	0.25	1.05	2.34	0.04	0.36	8	1.31
127	15	0.38	0.69	0.6	0.4	0.71	3.14	0.03	0.24	5.5	1.39
128	2	0.4	0.56	0.36	0.3	0.5	2.59	0.05	0.46	2.33	1.57
129	0	0.47	0.62	0.57	0.03	0.4	2.57	0.03	0.3	1	1.5
130	15	0.34	0.69	0.46	0.79	1.05	3.54	0.05	0.38	12.7	1.42
131	18	0.37	0.65	0.55	0.38	0.88	3.11	0.03	0.39	9.5	1.5
132	30	0.34	0.69	0.46	0.56	1.04	3.54	0.06	0.46	9.5	1.42
133	11	0.33	0.74	0.47	0.39	0.76	3.5	0.03	0.37	6.66	1.42
134	11	0.38	0.76	0.59	0.24	0.6	2.9	0.04	0.45	5	1.39
135	14	0.27	0.64	0.54	0.68	0.9	2.45	0.05	0.44	7.33	1.37

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Table A-2.2: Delay (Del) , and the ten summary measures (B1 ... B10) of the 135 Testnetworks scheduled by GRD.

No.	DEL	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
1	2	0.29	0.68	0.49	0.01	0.65	2.62	0.03	0.36	2	1.33
2	21	0.33	0.74	0.47	0.31	1.32	3.5	0.04	0.4	18	1.42
3	20	0.23	0.84	0.56	0.28	1.28	2.76	0.04	0.4	17	1.2
4	12	0.27	0.79	0.44	0.02	0.77	9.5	0.03	0.3	14	1.15
5	4	0.27	0.64	0.54	0.17	0.81	2.45	0.05	0.39	7	1.37
6	2	0.36	0.64	0.42	0.17	0.84	2.59	0.03	0.25	8	1.42
7	0	0.26	0.59	0.4	0.02	0.55	2.61	0.02	0.3	2	1.29
8	2	0.37	0.65	0.55	0.02	0.53	3.11	0.02	0.23	2	1.5
9	0	0.4	0.56	0.36	0.02	0.46	2.59	0.02	0.24	2	1.57
10	15	0.44	0.73	0.56	0.29	1.28	3.31	0.04	0.29	13	1.52
11	0	0.34	0.76	0.58	0	0.55	3.26	0.02	0.33	0	1.35
12	1	0.31	0.66	0.38	1.99	0.61	3.2	0.02	0.23	2	1.38
13	13	0.34	0.69	0.46	0.25	0.96	3.54	0.05	0.37	11	1.42
14	4	0.39	0.74	0.6	0.13	0.82	2.69	0.04	0.35	7	1.43
15	1	0.28	0.58	0.51	4.58	0.75	2.8	0.04	0.4	6	1.39
16	21	0.37	0.84	0.71	0.29	1.29	3.41	0.05	0.4	13	1.33
17	9	0.37	0.82	0.47	0.18	1	2.95	0.04	0.35	12	1.33
18	9	0.38	0.76	0.59	0.18	1.06	2.09	0.05	0.49	13	1.39
19	3	0.47	0.62	0.57	0.13	0.65	2.57	0.03	0.36	3	1.5
20	15	0.32	0.77	0.54	0.35	1.2	3.07	0.04	0.34	14	1.27
21	10	0.37	0.38	0.29	0.28	1.03	2.18	0.04	0.4	4	1.5
22	6	0.4	0.71	0.66	0.1	0.65	2.59	0.03	0.4	8	1.33
23	20	0.4	0.67	0.34	0.27	1.17	5.68	0.05	0.47	31	1.29
24	9	0.4	0.8	0.69	0.33	0.82	1.9	0.05	0.4	6	1.46
25	14	0.29	0.79	0.53	0.36	1.38	2.4	0.06	0.36	12	1.28
26	8	0.4	0.75	0.61	0.16	0.85	2.84	0.05	0.4	7	1.42
27	21	0.36	0.68	0.65	0.34	1.29	2.81	0.06	0.46	10	1.69
28	6	0.38	0.72	0.61	0.23	0.92	2.66	0.04	0.36	11	1.5
29	17	0.29	0.74	0.39	0.47	1.67	2.08	0.07	0.52	12	1.26
30	11	0.36	0.76	0.59	0.461	1.73	1.59	0.1	0.44	6	1.37
31	22	0.38	0.87	0.71	0.52	2.05	2.34	0.07	0.45	13	1.44
32	7	0.28	0.84	0.51	0.36	1.31	2.38	0.06	0.38	11	1.23
33	3	0.41	0.7	0.45	0.12	0.98	2.08	0.04	0.31	6	1.41
34	19	0.43	0.72	0.46	0.5	1.85	2.35	0.09	0.6	12	1.4
35	23	0.28	0.8	0.52	0.43	1.63	3.19	0.07	0.41	16	1.23
36	4	0.25	0.8	0.48	0.26	1.04	2.9	0.06	0.25	8	1.17
37	16	0.3	0.63	0.38	0.17	0.59	2.11	0.03	0.32	6	1.29
38	21	0.34	0.8	0.62	0.43	1.58	2.34	0.06	0.55	15	1.31
39	33	0.38	0.69	0.6	0.52	1.89	3.14	0.09	0.64	15	1.39
40	14	0.36	0.65	0.47	0.31	1.22	3.09	0.06	0.48	10	1.37
41	8	0.68	0.64	0.44	0.25	1.06	2.51	0.04	0.32	10	1.56
42	0	0.29	0.68	0.49	0	0.55	2.62	0.02	0.29	0	1.33
43	19	0.33	0.74	0.47	0.45	1.1	3.5	0.04	0.42	12	1.42
44	14	0.23	0.84	0.56	0.5	1.16	2.76	0.04	0.38	13	1.2
45	36	0.27	0.79	0.44	0.37	0.94	9.5	0.04	0.43	28	1.15

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Continue Table A-2.2

No.	DEL.	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
46	19	0.27	0.64	0.54	0.38	0.95	2.45	0.07	0.54	9.5	1.37
47	12	0.36	0.64	0.42	0.47	1	2.59	0.04	0.41	7	1.42
48	0	0.26	0.59	0.4	0.02	0.37	2.6	0.02	0.3	1	1.29
49	9	0.37	0.65	0.55	0.22	0.7	3.11	0.03	0.31	5.5	1.5
50	11	0.4	0.56	0.36	0.47	0.79	2.59	0.05	0.45	6.5	1.57
51	25	0.44	0.73	0.56	0.57	1.16	3.31	0.05	0.37	10.5	1.52
52	14	0.34	0.76	0.58	0.23	0.55	3.26	0.03	0.56	7.5	1.35
53	26	0.31	0.66	0.38	0.3	0.72	3.2	0.03	0.36	8.5	1.38
54	3	0.34	0.69	0.46	0.2	0.63	3.54	0.04	0.3	6.5	1.42
55	10	0.39	0.74	0.6	0.44	0.68	2.69	0.05	0.48	5	1.43
56	12	0.28	0.58	0.51	0.24	0.73	2.8	0.06	0.57	6.5	1.39
57	13	0.37	0.84	0.71	0.27	0.85	3.41	0.04	0.36	7.5	1.33
58	11	0.37	0.82	0.47	0.34	0.74	2.95	0.06	0.5	6.5	1.33
59	6	0.38	0.76	0.59	0.15	0.49	2.9	0.04	0.4	3.5	1.39
60	0	0.47	0.62	0.57	0.13	0.34	2.57	0.02	0.28	1.5	1.5
61	7	0.37	0.38	0.29	0.32	0.6	2.18	0.04	0.42	3.5	1.5
62	10	0.37	0.38	0.29	0.35	0.62	2.18	0.02	0.23	5	1.5
63	6	0.4	0.7	0.66	6.31	0.46	2.59	0.03	0.35	3	1.33
64	15	0.4	0.67	0.34	0.18	0.6	5.68	0.04	0.39	10.5	1.29
65	6	0.4	0.8	0.69	0.49	0.81	1.9	0.06	0.45	6	1.46
66	14	0.29	0.79	0.53	0.53	1.05	2.04	0.06	0.42	7.5	1.28
67	16	0.4	0.75	0.61	0.46	0.96	2.84	0.05	0.42	11.5	1.42
68	9	0.36	0.68	0.65	0.25	0.64	2.81	0.04	0.32	5	1.69
69	17	0.38	0.72	0.61	0.37	0.85	2.66	0.06	0.49	5.5	1.5
70	6	0.29	0.74	0.39	0.3	0.7	2.08	0.04	0.35	3	1.26
71	18	0.36	0.76	0.59	0.98	1.77	1.59	0.13	0.58	6.5	1.37
72	40	0.38	0.87	0.717	1.13	2.56	2.34	0.1	0.65	13	1.44
73	15	0.28	0.84	0.51	0.73	1.39	2.38	0.09	0.53	9	1.23
74	13	0.41	0.7	0.45	0.47	1	2.08	0.05	0.42	7	1.4
75	22	0.43	0.72	0.46	0.66	1.24	2.35	0.07	0.43	7	1.47
76	39	0.28	0.8	0.52	0.65	1.32	3.19	0.09	0.55	10	1.23
77	15	0.25	0.8	0.48	0.68	1.13	2.9	0.1	0.38	7.5	1.17
78	10	0.3	0.63	0.38	0.32	0.68	2.11	0.04	0.49	3.5	1.29
79	5	0.34	0.8	0.62	0.32	0.63	2.34	0.02	0.22	5.5	1.31
80	17	0.38	0.69	0.6	0.4	0.71	3.14	0.03	0.24	5.5	1.39
81	14	0.36	0.65	0.47	0.31	1.22	3.09	0.06	0.48	10	1.37
82	19	0.68	0.64	0.44	0.43	1.6	2.51	0.06	0.48	12	1.56
83	11	0.29	0.68	0.49	0.1	0.53	2.62	0.03	0.34	2.33	1.33
84	0	0.33	0.74	0.47	0.18	0.6	3.5	0.02	0.27	4.66	1.42
85	20	0.27	0.79	0.44	0.27	0.64	9.5	0.03	0.37	13	1.15
86	8	0.23	0.84	0.56	0.22	0.61	2.76	0.02	0.25	3.66	1.2
87	15	0.36	0.64	0.42	0.46	0.84	2.59	0.04	0.35	7.66	1.428
88	13	0.27	0.64	0.54	0.43	0.72	2.45	0.04	0.35	5.66	1.37
89	15	0.37	0.65	0.55	0.44	0.65	3.11	0.03	0.35	5.66	1.37
90	6	0.26	0.59	0.4	0.33	0.64	2.6	0.03	0.32	7	1.5

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Continue Table A-2.2

No.	DEL.	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
91	50	0.44	0.73	0.56	1.39	1.58	3.31	0.07	0.47	8.33	1.29
92	6	0.4	0.56	0.36	0.23	0.46	2.59	0.03	0.36	2	1.57
93	4	0.31	0.66	0.38	0.15	0.61	3.2	0.03	0.37	3	1.38
94	13	0.34	0.76	0.58	0.36	0.67	3.26	0.04	0.6	8.33	1.35
95	0	0.39	0.74	0.6	0	0.5	2.69	0.02	0.23	2	1.43
96	14	0.34	0.69	0.46	0.61	0.94	3.54	0.05	0.34	11.33	1.42
97	28	0.37	0.84	0.71	0.58	1.03	3.41	0.05	0.42	8	1.33
98	0	0.28	0.58	0.51	0	0..39	2.8	0.02	0.26	0	1.39
99	19	0.37	0.82	0.47	1	1.2	2.95	0.07	0.53	9.33	1.33
100	6	0.38	0.76	0.59	0.33	0.54	2.9	0.04	0.36	3.33	1.39
101	0	0.47	0.62	0.57	0.03	0.4	2.57	0.03	0.3	1	1.5
102	7	0.37	0.38	0.29	0.57	0.55	2.18	0.03	0.36	2.66	1.5
103	12	0.37	0.38	0.29	0.54	0.63	2.18	0.04	0.42	3.33	1.5
104	6	0.4	0.71	0.66	0.13	0,49	2.59	0.03	0.41	1	1.33
105	10	0.4	0.67	0.34	0.48	0.68	5.68	0.05	0.4	10.33	1.29
106	4	0.4	0.8	0.69	0.39	0.51	1.9	0.04	0.3	3.66	1.46
107	26	0.29	0.79	0.53	0.89	1.12	2.4	0.07	0.44	7	1.28
108	3	0.4	0.75	0.61	8.11	0.5	2.84	0.03	0.3	2	1.42
109	16	0.36	0.68	0.65	0.61	0.93	2.81	0.05	0.4	7.33	1.69
110	5	0.38	0.72	0.61	0.22	0.67	2.66	0.04	0.41	4	1.5
111	20	0.29	0.74	0.39	0.65	0.89	2.08	0.07	0.51	5	1.26
112	9	0.36	0.76	0.59	1.08	1.32	1.59	0.1	0.46	5.33	1.37
113	15	0.38	0.87	0.71	0.53	1.11	2.34	0.06	0.41	6.33	1.44
114	15	0.28	0.84	0.51	0.83	1.16	2.38	0.07	0.46	8	1.23
115	13	0.41	0.7	0.45	0.52	0.93	2.08	0.06	0.52	5	1.41
116	34	0.43	0.72	0.46	1.3	1.78	2.35	0.09	0.59	11	1.47
117	23	0.28	0.8	0.52	0.78	0.92	3.19	0.06	0.42	6.33	1.23
118	17	0.25	0.8	0.48	1.28	1.35	2.9	0.12	0.47	9	1.17
119	0	0.3	0.63	0.38	0.53	0.56	2.11	0.02	0.29	5.33	1.29
120	8	0.34	0.8	0.62	0.45	0.62	2.3	0.04	0.36	3.33	1.31
121	38	0.38	0.69	0.6	1.28	1.54	3.14	0.07	0.54	13.66	1.39
122	15	0.36	0.65	0.47	0.43	0.66	3.09	0.04	0.38	5.66	1.37
123	9	0.68	0.64	0.44	0.44	0.57	2.51	0.04	0.35	3.33	1.562
124	6	0.23	0.84	0.56	0.15	0.56	2.76	0.02	0.24	2.66	1.2
125	0	0.29	0.68	0.49	0	0.55	2.62	0.02	0.29	0	1.33
126	7	0.34	0.8	0.62	0.25	1.05	2.34	0.04	0.36	8	1.31
127	17	0.38	0.69	0.6	0.4	0.71	3.14	0.03	0.24	5.5	1.39
128	6	0.4	0.56	0.36	0.3	0.5	2.59	0.05	0.46	2.33	1.57
129	0	0.47	0.62	0.57	0.03	0.4	2.57	0.03	0.3	1	1.5
130	15	0.34	0.69	0.46	0.79	1.05	3.54	0.05	0.38	12.66	1.42
131	18	0.37	0.65	0.55	0.38	0.88	3.11	0.03	0.39	9.5	1.5
132	26	0.34	0.69	0.46	0.56	1.04	3.54	0.06	0.46	9.5	1.42
133	12	0.33	0.74	0.47	0.39	0.76	3.5	0.03	0.37	6.66	1.42
134	9	0.38	0.76	0.59	0.24	0.6	2.9	0.04	0.45	5	1.39
135	13	0.27	0.64	0.54	0.68	0.9	2.45	0.05	0.44	7.33	1.37

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Table A-2.3: Delay (Del) , and the ten summary measures (B1 ... B10) of the 135 Testnetworks scheduled by STF.

No.	DEL	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
1	0	0.29	0.68	0.49	0.01	0.65	2.62	0.03	0.36	2	1.33
2	22	0.33	0.74	0.47	0.31	1.32	3.5	0.04	0.4	18	1.42
3	17	0.23	0.84	0.56	0.28	1.28	2.76	0.04	0.4	17	1.2
4	5	0.27	0.79	0.44	0.02	0.77	9.5	0.03	0.3	14	1.15
5	6	0.27	0.64	0.54	0.17	0.81	2.45	0.05	0.39	7	1.37
6	4	0.36	0.64	0.42	0.17	0.84	2.59	0.03	0.25	8	1.42
7	0	0.26	0.59	0.4	0.02	0.55	2.61	0.02	0.3	2	1.29
8	2	0.37	0.65	0.55	0.02	0.53	3.11	0.02	0.23	2	1.5
9	2	0.4	0.56	0.36	0.02	0.46	2.59	0.02	0.24	2	1.57
10	14	0.44	0.73	0.56	0.29	1.28	3.31	0.04	0.29	13	1.52
11	0	0.34	0.76	0.58	0	0.55	3.26	0.02	0.33	0	1.35
12	1	0.31	0.66	0.38	1.99	0.61	3.2	0.02	0.23	2	1.38
13	10	0.34	0.69	0.46	0.25	0.96	3.54	0.05	0.37	11	1.42
14	7	0.39	0.74	0.6	0.13	0.82	2.69	0.04	0.35	7	1.43
15	1	0.28	0.58	0.51	4.58	0.75	2.8	0.04	0.4	6	1.39
16	22	0.37	0.84	0.71	0.29	1.29	3.41	0.05	0.4	13	1.33
17	10	0.37	0.82	0.47	0.18	1	2.95	0.04	0.35	12	1.33
18	12	0.38	0.76	0.59	0.18	1.06	2.09	0.05	0.49	13	1.39
19	3	0.47	0.62	0.57	0.13	0.65	2.57	0.03	0.36	3	1.5
20	13	0.32	0.77	0.54	0.35	1.2	3.07	0.04	0.34	14	1.27
21	12	0.37	0.38	0.29	0.28	1.03	2.18	0.04	0.4	4	1.5
22	6	0.4	0.71	0.66	0.1	0.65	2.59	0.03	0.4	8	1.33
23	23	0.4	0.67	0.34	0.27	1.17	5.68	0.05	0.47	31	1.29
24	13	0.4	0.8	0.69	0.33	0.82	1.9	0.05	0.4	6	1.46
25	14	0.29	0.79	0.53	0.36	1.38	2.4	0.06	0.36	12	1.28
26	4	0.4	0.75	0.61	0.16	0.85	2.84	0.05	0.4	7	1.42
27	12	0.36	0.68	0.65	0.34	1.29	2.81	0.06	0.46	10	1.69
28	12	0.38	0.72	0.61	0.23	0.92	2.66	0.04	0.36	11	1.5
29	21	0.29	0.74	0.39	0.47	1.67	2.08	0.07	0.52	12	1.26
30	10	0.36	0.76	0.59	0.461	1.73	1.59	0.1	0.44	6	1.37
31	22	0.38	0.87	0.71	0.52	2.05	2.34	0.07	0.45	13	1.44
32	13	0.28	0.84	0.51	0.36	1.31	2.38	0.06	0.38	11	1.23
33	3	0.41	0.7	0.45	0.12	0.98	2.08	0.04	0.31	6	1.41
34	18	0.43	0.72	0.46	0.5	1.85	2.35	0.09	0.6	12	1.4
35	26	0.28	0.8	0.52	0.43	1.63	3.19	0.07	0.41	16	1.23
36	6	0.25	0.8	0.48	0.26	1.04	2.9	0.06	0.25	8	1.17
37	18	0.3	0.63	0.38	0.17	0.59	2.11	0.03	0.32	6	1.29
38	22	0.34	0.8	0.62	0.43	1.58	2.34	0.06	0.55	15	1.31
39	36	0.38	0.69	0.6	0.52	1.89	3.14	0.09	0.64	15	1.39
40	14	0.36	0.65	0.47	0.31	1.22	3.09	0.06	0.48	10	1.37
41	8	0.68	0.64	0.44	0.25	1.06	2.51	0.04	0.32	10	1.56
42	0	0.29	0.68	0.49	0	0.55	2.62	0.02	0.29	0	1.33
43	13	0.33	0.74	0.47	0.45	1.1	3.5	0.04	0.42	12	1.42
44	15	0.23	0.84	0.56	0.5	1.16	2.76	0.04	0.38	13	1.2
45	35	0.27	0.79	0.44	0.37	0.94	9.5	0.04	0.43	28	1.15

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Continue Table A-2.3

No.	DEL	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
46	19	0.27	0.64	0.54	0.38	0.95	2.45	0.07	0.54	9.5	1.37
47	12	0.36	0.64	0.42	0.47	1	2.59	0.04	0.41	7	1.42
48	0	0.26	0.59	0.4	0.02	0.37	2.6	0.02	0.3	1	1.29
49	11	0.37	0.65	0.55	0.22	0.7	3.11	0.03	0.31	5.5	1.5
50	10	0.4	0.56	0.36	0.47	0.79	2.59	0.05	0.45	6.5	1.57
51	29	0.44	0.73	0.56	0.57	1.16	3.31	0.05	0.37	10.5	1.52
52	14	0.34	0.76	0.58	0.23	0.55	3.26	0.03	0.56	7.5	1.35
53	13	0.31	0.66	0.38	0.3	0.72	3.2	0.03	0.36	8.5	1.38
54	7	0.34	0.69	0.46	0.2	0.63	3.54	0.04	0.3	6.5	1.42
55	16	0.39	0.74	0.6	0.44	0.68	2.69	0.05	0.48	5	1.43
56	4	0.28	0.58	0.51	0.24	0.73	2.8	0.06	0.57	6.5	1.39
57	11	0.37	0.84	0.71	0.27	0.85	3.41	0.04	0.36	7.5	1.33
58	12	0.37	0.82	0.47	0.34	0.74	2.95	0.06	0.5	6.5	1.33
59	6	0.38	0.76	0.59	0.15	0.49	2.9	0.04	0.4	3.5	1.39
60	0	0.47	0.62	0.57	0.13	0.34	2.57	0.02	0.28	1.5	1.5
61	8	0.37	0.38	0.29	0.32	0.6	2.18	0.04	0.42	3.5	1.5
62	12	0.37	0.38	0.29	0.35	0.62	2.18	0.02	0.23	5	1.5
63	6	0.4	0.7	0.66	6.31	0.46	2.59	0.03	0.35	3	1.33
64	30	0.4	0.67	0.34	0.18	0.6	5.68	0.04	0.39	10.5	1.29
65	8	0.4	0.8	0.69	0.49	0.81	1.9	0.06	0.45	6	1.46
66	22	0.29	0.79	0.53	0.53	1.05	2.04	0.06	0.42	7.5	1.28
67	17	0.4	0.75	0.61	0.46	0.96	2.84	0.05	0.42	11.5	1.42
68	5	0.36	0.68	0.65	0.25	0.64	2.81	0.04	0.32	5	1.69
69	16	0.38	0.72	0.61	0.37	0.85	2.66	0.06	0.49	5.5	1.5
70	8	0.29	0.74	0.39	0.3	0.7	2.08	0.04	0.35	3	1.26
71	18	0.36	0.76	0.59	0.98	1.77	1.59	0.13	0.58	6.5	1.37
72	44	0.38	0.87	0.717	1.13	2.56	2.34	0.1	0.65	13	1.44
73	19	0.28	0.84	0.51	0.73	1.39	2.38	0.09	0.53	9	1.23
74	14	0.41	0.7	0.45	0.47	1	2.08	0.05	0.42	7	1.4
75	24	0.43	0.72	0.46	0.66	1.24	2.35	0.07	0.43	7	1.47
76	25	0.28	0.8	0.52	0.65	1.32	3.19	0.09	0.55	10	1.23
77	17	0.25	0.8	0.48	0.68	1.13	2.9	0.1	0.38	7.5	1.17
78	12	0.3	0.63	0.38	0.32	0.68	2.11	0.04	0.49	3.5	1.29
79	7	0.34	0.8	0.62	0.32	0.63	2.34	0.02	0.22	5.5	1.31
80	20	0.38	0.69	0.6	0.4	0.71	3.14	0.03	0.24	5.5	1.39
81	14	0.36	0.65	0.47	0.31	1.22	3.09	0.06	0.48	10	1.37
82	21	0.68	0.64	0.44	0.43	1.6	2.51	0.06	0.48	12	1.56
83	7	0.29	0.68	0.49	0.1	0.53	2.62	0.03	0.34	2.33	1.33
84	5	0.33	0.74	0.47	0.18	0.6	3.5	0.02	0.27	4.66	1.42
85	22	0.27	0.79	0.44	0.27	0.64	9.5	0.03	0.37	13	1.15
86	5	0.23	0.84	0.56	0.22	0.61	2.76	0.02	0.25	3.66	1.2
87	13	0.36	0.64	0.42	0.46	0.84	2.59	0.04	0.35	7.66	1.428
88	11	0.27	0.64	0.54	0.43	0.72	2.45	0.04	0.35	5.66	1.37
89	15	0.37	0.65	0.55	0.44	0.65	3.11	0.03	0.35	5.66	1.37
90	0	0.26	0.59	0.4	0.33	0.64	2.6	0.03	0.32	7	1.5

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Continue Table A-2.3

No.	DEL	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
91	48	0.44	0.73	0.56	1.39	1.58	3.31	0.07	0.47	8.33	1.29
92	7	0.4	0.56	0.36	0.23	0.46	2.59	0.03	0.36	2	1.57
93	9	0.31	0.66	0.38	0.15	0.61	3.2	0.03	0.37	3	1.38
94	17	0.34	0.76	0.58	0.36	0.67	3.26	0.04	0.6	8.33	1.35
95	0	0.39	0.74	0.6	0	0.5	2.69	0.02	0.23	2	1.43
96	15	0.34	0.69	0.46	0.61	0.94	3.54	0.05	0.34	11.3	1.42
97	30	0.37	0.84	0.71	0.58	1.03	3.41	0.05	0.42	8	1.33
98	0	0.28	0.58	0.51	0	0.39	2.8	0.02	0.26	0	1.39
99	18	0.37	0.82	0.47	1	1.2	2.95	0.07	0.53	9.33	1.33
100	6	0.38	0.76	0.59	0.33	0.54	2.9	0.04	0.36	3.33	1.39
101	3	0.47	0.62	0.57	0.03	0.4	2.57	0.03	0.3	1	1.5
102	7	0.37	0.38	0.29	0.57	0.55	2.18	0.03	0.36	2.66	1.5
103	10	0.37	0.38	0.29	0.54	0.63	2.18	0.04	0.42	3.33	1.5
104	0	0.4	0.71	0.66	0.13	0.49	2.59	0.03	0.41	1	1.33
105	31	0.4	0.67	0.34	0.48	0.68	5.68	0.05	0.4	10.3	1.29
106	5	0.4	0.8	0.69	0.39	0.51	1.9	0.04	0.3	3.66	1.46
107	22	0.29	0.79	0.53	0.89	1.12	2.4	0.07	0.44	7	1.28
108	0	0.4	0.75	0.61	8.11	0.5	2.84	0.03	0.3	2	1.42
109	16	0.36	0.68	0.65	0.61	0.93	2.81	0.05	0.4	7.33	1.69
110	5	0.38	0.72	0.61	0.22	0.67	2.66	0.04	0.41	4	1.5
111	15	0.29	0.74	0.39	0.65	0.89	2.08	0.07	0.51	5	1.26
112	12	0.36	0.76	0.59	1.08	1.32	1.59	0.1	0.46	5.33	1.37
113	15	0.38	0.87	0.71	0.53	1.11	2.34	0.06	0.41	6.33	1.44
114	16	0.28	0.84	0.51	0.83	1.16	2.38	0.07	0.46	8	1.23
115	14	0.41	0.7	0.45	0.52	0.93	2.08	0.06	0.52	5	1.41
116	31	0.43	0.72	0.46	1.3	1.78	2.35	0.09	0.59	11	1.47
117	19	0.28	0.8	0.52	0.78	0.92	3.19	0.06	0.42	6.33	1.23
118	19	0.25	0.8	0.48	1.28	1.35	2.9	0.12	0.47	9	1.17
119	3	0.3	0.63	0.38	0.53	0.56	2.11	0.02	0.29	5.33	1.29
120	8	0.34	0.8	0.62	0.45	0.62	2.3	0.04	0.36	3.33	1.31
121	37	0.38	0.69	0.6	1.28	1.54	3.14	0.07	0.54	13.7	1.39
122	9	0.36	0.65	0.47	0.43	0.66	3.09	0.04	0.38	5.66	1.37
123	11	0.68	0.64	0.44	0.44	0.57	2.51	0.04	0.35	3.33	1.562
124	6	0.23	0.84	0.56	0.15	0.56	2.76	0.02	0.24	2.66	1.2
125	0	0.29	0.68	0.49	0	0.55	2.62	0.02	0.29	0	1.33
126	8	0.34	0.8	0.62	0.25	1.05	2.34	0.04	0.36	8	1.31
127	20	0.38	0.69	0.6	0.4	0.71	3.14	0.03	0.24	5.5	1.39
128	7	0.4	0.56	0.36	0.3	0.5	2.59	0.05	0.46	2.33	1.57
129	7	0.47	0.62	0.57	0.03	0.4	2.57	0.03	0.3	1	1.5
130	15	0.34	0.69	0.46	0.79	1.05	3.54	0.05	0.38	12.7	1.42
131	23	0.37	0.65	0.55	0.38	0.88	3.11	0.03	0.39	9.5	1.5
132	28	0.34	0.69	0.46	0.56	1.04	3.54	0.06	0.46	9.5	1.42
133	9	0.33	0.74	0.47	0.39	0.76	3.5	0.03	0.37	6.66	1.42
134	9	0.38	0.76	0.59	0.24	0.6	2.9	0.04	0.45	5	1.39
135	14	0.27	0.64	0.54	0.68	0.9	2.45	0.05	0.44	7.33	1.37

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Table A-2.4: Delay (Del) , and the ten summary measures (B1 ... B10) of the 135 Testnetworks scheduled by MINSLK & GRD.

No.	DEL	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
1	0	0.29	0.68	0.49	0.01	0.65	2.62	0.03	0.36	2	1.33
2	19	0.33	0.74	0.47	0.31	1.32	3.5	0.04	0.4	18	1.42
3	22	0.23	0.84	0.56	0.28	1.28	2.76	0.04	0.4	17	1.2
4	1	0.27	0.79	0.44	0.02	0.77	9.5	0.03	0.3	14	1.15
5	6	0.27	0.64	0.54	0.17	0.81	2.45	0.05	0.39	7	1.37
6	0	0.36	0.64	0.42	0.17	0.84	2.59	0.03	0.25	8	1.42
7	0	0.26	0.59	0.4	0.02	0.55	2.61	0.02	0.3	2	1.29
8	0	0.37	0.65	0.55	0.02	0.53	3.11	0.02	0.23	2	1.5
9	0	0.4	0.56	0.36	0.02	0.46	2.59	0.02	0.24	2	1.57
10	14	0.44	0.73	0.56	0.29	1.28	3.31	0.04	0.29	13	1.52
11	0	0.34	0.76	0.58	0	0.55	3.26	0.02	0.33	0	1.35
12	1	0.31	0.66	0.38	1.99	0.61	3.2	0.02	0.23	2	1.38
13	13	0.34	0.69	0.46	0.25	0.96	3.54	0.05	0.37	11	1.42
14	6	0.39	0.74	0.6	0.13	0.82	2.69	0.04	0.35	7	1.43
15	1	0.28	0.58	0.51	4.58	0.75	2.8	0.04	0.4	6	1.39
16	21	0.37	0.84	0.71	0.29	1.29	3.41	0.05	0.4	13	1.33
17	8	0.37	0.82	0.47	0.18	1	2.95	0.04	0.35	12	1.33
18	14	0.38	0.76	0.59	0.18	1.06	2.09	0.05	0.49	13	1.39
19	2	0.47	0.62	0.57	0.13	0.65	2.57	0.03	0.36	3	1.5
20	14	0.32	0.77	0.54	0.35	1.2	3.07	0.04	0.34	14	1.27
21	8	0.37	0.38	0.29	0.28	1.03	2.18	0.04	0.4	4	1.5
22	3	0.4	0.71	0.66	0.1	0.65	2.59	0.03	0.4	8	1.33
23	28	0.4	0.67	0.34	0.27	1.17	5.68	0.05	0.47	31	1.29
24	8	0.4	0.8	0.69	0.33	0.82	1.9	0.05	0.4	6	1.46
25	13	0.29	0.79	0.53	0.36	1.38	2.4	0.06	0.36	12	1.28
26	7	0.4	0.75	0.61	0.16	0.85	2.84	0.05	0.4	7	1.42
27	13	0.36	0.68	0.65	0.34	1.29	2.81	0.06	0.46	10	1.69
28	7	0.38	0.72	0.61	0.23	0.92	2.66	0.04	0.36	11	1.5
29	25	0.29	0.74	0.39	0.47	1.67	2.08	0.07	0.52	12	1.26
30	7	0.36	0.76	0.59	0.461	1.73	1.59	0.1	0.44	6	1.37
31	23	0.38	0.87	0.71	0.52	2.05	2.34	0.07	0.45	13	1.44
32	11	0.28	0.84	0.51	0.36	1.31	2.38	0.06	0.38	11	1.23
33	2	0.41	0.7	0.45	0.12	0.98	2.08	0.04	0.31	6	1.41
34	2	0.43	0.72	0.46	0.5	1.85	2.35	0.09	0.6	12	1.4
35	25	0.28	0.8	0.52	0.43	1.63	3.19	0.07	0.41	16	1.23
36	9	0.25	0.8	0.48	0.26	1.04	2.9	0.06	0.25	8	1.17
37	13	0.3	0.63	0.38	0.17	0.59	2.11	0.03	0.32	6	1.29
38	30	0.34	0.8	0.62	0.43	1.58	2.34	0.06	0.55	15	1.31
39	32	0.38	0.69	0.6	0.52	1.89	3.14	0.09	0.64	15	1.39
40	16	0.36	0.65	0.47	0.31	1.22	3.09	0.06	0.48	10	1.37
41	9	0.68	0.64	0.44	0.25	1.06	2.51	0.04	0.32	10	1.56
42	0	0.29	0.68	0.49	0	0.55	2.62	0.02	0.29	0	1.33
43	16	0.33	0.74	0.47	0.45	1.1	3.5	0.04	0.42	12	1.42
44	18	0.23	0.84	0.56	0.5	1.16	2.76	0.04	0.38	13	1.2
45	66	0.27	0.79	0.44	0.37	0.94	9.5	0.04	0.43	28	1.15

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Continue Table A-2.4

No.	DEL	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
46	16	0.27	0.64	0.54	0.38	0.95	2.45	0.07	0.54	9.5	1.37
47	10	0.36	0.64	0.42	0.47	1	2.59	0.04	0.41	7	1.42
48	0	0.26	0.59	0.4	0.02	0.37	2.6	0.02	0.3	1	1.29
49	7	0.37	0.65	0.55	0.22	0.7	3.11	0.03	0.31	5.5	1.5
50	5	0.4	0.56	0.36	0.47	0.79	2.59	0.05	0.45	6.5	1.57
51	5	0.44	0.73	0.56	0.57	1.16	3.31	0.05	0.37	10.5	1.52
52	16	0.34	0.76	0.58	0.23	0.55	3.26	0.03	0.56	7.5	1.35
53	20	0.31	0.66	0.38	0.3	0.72	3.2	0.03	0.36	8.5	1.38
54	11	0.34	0.69	0.46	0.2	0.63	3.54	0.04	0.3	6.5	1.42
55	10	0.39	0.74	0.6	0.44	0.68	2.69	0.05	0.48	5	1.43
56	12	0.28	0.58	0.51	0.24	0.73	2.8	0.06	0.57	6.5	1.39
57	12	0.37	0.84	0.71	0.27	0.85	3.41	0.04	0.36	7.5	1.33
58	14	0.37	0.82	0.47	0.34	0.74	2.95	0.06	0.5	6.5	1.33
59	11	0.38	0.76	0.59	0.15	0.49	2.9	0.04	0.4	3.5	1.39
60	0	0.47	0.62	0.57	0.13	0.34	2.57	0.02	0.28	1.5	1.5
61	3	0.37	0.38	0.29	0.32	0.6	2.18	0.04	0.42	3.5	1.5
62	8	0.37	0.38	0.29	0.35	0.62	2.18	0.02	0.23	5	1.5
63	3	0.4	0.7	0.66	6.31	0.46	2.59	0.03	0.35	3	1.33
64	21	0.4	0.67	0.34	0.18	0.6	5.68	0.04	0.39	10.5	1.29
65	6	0.4	0.8	0.69	0.49	0.81	1.9	0.06	0.45	6	1.46
66	19	0.29	0.79	0.53	0.53	1.05	2.04	0.06	0.42	7.5	1.28
67	13	0.4	0.75	0.61	0.46	0.96	2.84	0.05	0.42	11.5	1.42
68	5	0.36	0.68	0.65	0.25	0.64	2.81	0.04	0.32	5	1.69
69	17	0.38	0.72	0.61	0.37	0.85	2.66	0.06	0.49	5.5	1.5
70	8	0.29	0.74	0.39	0.3	0.7	2.08	0.04	0.35	3	1.26
71	18	0.36	0.76	0.59	0.98	1.77	1.59	0.13	0.58	6.5	1.37
72	44	0.38	0.87	0.717	1.13	2.56	2.34	0.1	0.65	13	1.44
73	17	0.28	0.84	0.51	0.73	1.39	2.38	0.09	0.53	9	1.23
74	15	0.41	0.7	0.45	0.47	1	2.08	0.05	0.42	7	1.4
75	22	0.43	0.72	0.46	0.66	1.24	2.35	0.07	0.43	7	1.47
76	26	0.28	0.8	0.52	0.65	1.32	3.19	0.09	0.55	10	1.23
77	14	0.25	0.8	0.48	0.68	1.13	2.9	0.1	0.38	7.5	1.17
78	11	0.3	0.63	0.38	0.32	0.68	2.11	0.04	0.49	3.5	1.29
79	6	0.34	0.8	0.62	0.32	0.63	2.34	0.02	0.22	5.5	1.31
80	15	0.38	0.69	0.6	0.4	0.71	3.14	0.03	0.24	5.5	1.39
81	16	0.36	0.65	0.47	0.31	1.22	3.09	0.06	0.48	10	1.37
82	23	0.68	0.64	0.44	0.43	1.6	2.51	0.06	0.48	12	1.56
83	12	0.29	0.68	0.49	0.1	0.53	2.62	0.03	0.34	2.33	1.33
84	4	0.33	0.74	0.47	0.18	0.6	3.5	0.02	0.27	4.66	1.42
85	13	0.27	0.79	0.44	0.27	0.64	9.5	0.03	0.37	13	1.15
86	6	0.23	0.84	0.56	0.22	0.61	2.76	0.02	0.25	3.66	1.2
87	15	0.36	0.64	0.42	0.46	0.84	2.59	0.04	0.35	7.66	1.428
88	7	0.27	0.64	0.54	0.43	0.72	2.45	0.04	0.35	5.66	1.37
89	15	0.37	0.65	0.55	0.44	0.65	3.11	0.03	0.35	5.66	1.37
90	0	0.26	0.59	0.4	0.33	0.64	2.6	0.03	0.32	7	1.5

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Continue Table A-2.4

No.	DEL	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
91	39	0.44	0.73	0.56	1.39	1.58	3.31	0.07	0.47	8.33	1.29
92	2	0.4	0.56	0.36	0.23	0.46	2.59	0.03	0.36	2	1.57
93	1	0.31	0.66	0.38	0.15	0.61	3.2	0.03	0.37	3	1.38
94	13	0.34	0.76	0.58	0.36	0.67	3.26	0.04	0.6	8.33	1.35
95	0	0.39	0.74	0.6	0	0.5	2.69	0.02	0.23	2	1.43
96	13	0.34	0.69	0.46	0.61	0.94	3.54	0.05	0.34	11.3	1.42
97	29	0.37	0.84	0.71	0.58	1.03	3.41	0.05	0.42	8	1.33
98	0	0.28	0.58	0.51	0	0.39	2.8	0.02	0.26	0	1.39
99	16	0.37	0.82	0.47	1	1.2	2.95	0.07	0.53	9.33	1.33
100	11	0.38	0.76	0.59	0.33	0.54	2.9	0.04	0.36	3.33	1.39
101	0	0.47	0.62	0.57	0.03	0.4	2.57	0.03	0.3	1	1.5
102	6	0.37	0.38	0.29	0.57	0.55	2.18	0.03	0.36	2.66	1.5
103	9	0.37	0.38	0.29	0.54	0.63	2.18	0.04	0.42	3.33	1.5
104	6	0.4	0.71	0.66	0.13	0.49	2.59	0.03	0.41	1	1.33
105	20	0.4	0.67	0.34	0.48	0.68	5.68	0.05	0.4	10.3	1.29
106	3	0.4	0.8	0.69	0.39	0.51	1.9	0.04	0.3	3.66	1.46
107	26	0.29	0.79	0.53	0.89	1.12	2.4	0.07	0.44	7	1.28
108	0	0.4	0.75	0.61	8.11	0.5	2.84	0.03	0.3	2	1.42
109	17	0.36	0.68	0.65	0.61	0.93	2.81	0.05	0.4	7.33	1.69
110	6	0.38	0.72	0.61	0.22	0.67	2.66	0.04	0.41	4	1.5
111	14	0.29	0.74	0.39	0.65	0.89	2.08	0.07	0.51	5	1.26
112	11	0.36	0.76	0.59	1.08	1.32	1.59	0.1	0.46	5.33	1.37
113	19	0.38	0.87	0.71	0.53	1.11	2.34	0.06	0.41	6.33	1.44
114	19	0.28	0.84	0.51	0.83	1.16	2.38	0.07	0.46	8	1.23
115	14	0.41	0.7	0.45	0.52	0.93	2.08	0.06	0.52	5	1.41
116	33	0.43	0.72	0.46	1.3	1.78	2.35	0.09	0.59	11	1.47
117	18	0.28	0.8	0.52	0.78	0.92	3.19	0.06	0.42	6.33	1.23
118	35	0.25	0.8	0.48	1.28	1.35	2.9	0.12	0.47	9	1.17
119	5	0.3	0.63	0.38	0.53	0.56	2.11	0.02	0.29	5.33	1.29
120	5	0.34	0.8	0.62	0.45	0.62	2.3	0.04	0.36	3.33	1.31
121	38	0.38	0.69	0.6	1.28	1.54	3.14	0.07	0.54	13.7	1.39
122	8	0.36	0.65	0.47	0.43	0.66	3.09	0.04	0.38	5.66	1.37
123	11	0.68	0.64	0.44	0.44	0.57	2.51	0.04	0.35	3.33	1.562
124	6	0.23	0.84	0.56	0.15	0.56	2.76	0.02	0.24	2.66	1.2
125	0	0.29	0.68	0.49	0	0.55	2.62	0.02	0.29	0	1.33
126	8	0.34	0.8	0.62	0.25	1.05	2.34	0.04	0.36	8	1.31
127	15	0.38	0.69	0.6	0.4	0.71	3.14	0.03	0.24	5.5	1.39
128	2	0.4	0.56	0.36	0.3	0.5	2.59	0.05	0.46	2.33	1.57
129	0	0.47	0.62	0.57	0.03	0.4	2.57	0.03	0.3	1	1.5
130	15	0.34	0.69	0.46	0.79	1.05	3.54	0.05	0.38	12.7	1.42
131	18	0.37	0.65	0.55	0.38	0.88	3.11	0.03	0.39	9.5	1.5
132	29	0.34	0.69	0.46	0.56	1.04	3.54	0.06	0.46	9.5	1.42
133	11	0.33	0.74	0.47	0.39	0.76	3.5	0.03	0.37	6.66	1.42
134	11	0.38	0.76	0.59	0.24	0.6	2.9	0.04	0.45	5	1.39
135	14	0.27	0.64	0.54	0.68	0.9	2.45	0.05	0.44	7.33	1.37

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Table A-2.5: Delay (Del) , and the ten summary measures (B1 ... B10) of the 135 Testnetworks scheduled by STF & GRD.

No.	DEL	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
1	0	0.29	0.68	0.49	0.01	0.65	2.62	0.03	0.36	2	1.33
2	22	0.33	0.74	0.47	0.31	1.32	3.5	0.04	0.4	18	1.42
3	16	0.23	0.84	0.56	0.28	1.28	2.76	0.04	0.4	17	1.2
4	5	0.27	0.79	0.44	0.02	0.77	9.5	0.03	0.3	14	1.15
5	5	0.27	0.64	0.54	0.17	0.81	2.45	0.05	0.39	7	1.37
6	3	0.36	0.64	0.42	0.17	0.84	2.59	0.03	0.25	8	1.42
7	0	0.26	0.59	0.4	0.02	0.55	2.61	0.02	0.3	2	1.29
8	2	0.37	0.65	0.55	0.02	0.53	3.11	0.02	0.23	2	1.5
9	2	0.4	0.56	0.36	0.02	0.46	2.59	0.02	0.24	2	1.57
10	14	0.44	0.73	0.56	0.29	1.28	3.31	0.04	0.29	13	1.52
11	0	0.34	0.76	0.58	0.	0.55	3.26	0.02	0.33	0	1.35
12	1	0.31	0.66	0.38	1.99	0.61	3.2	0.02	0.23	2	1.38
13	10	0.34	0.69	0.46	0.25	0.96	3.54	0.05	0.37	11	1.42
14	7	0.39	0.74	0.6	0.13	0.82	2.69	0.04	0.35	7	1.43
15	1	0.28	0.58	0.51	4.58	0.75	2.8	0.04	0.4	6	1.39
16	21	0.37	0.84	0.71	0.29	1.29	3.41	0.05	0.4	13	1.33
17	8	0.37	0.82	0.47	0.18	1	2.95	0.04	0.35	12	1.33
18	9	0.38	0.76	0.59	0.18	1.06	2.09	0.05	0.49	13	1.39
19	6	0.47	0.62	0.57	0.13	0.65	2.57	0.03	0.36	3	1.5
20	12	0.32	0.77	0.54	0.35	1.2	3.07	0.04	0.34	14	1.27
21	11	0.37	0.38	0.29	0.28	1.03	2.18	0.04	0.4	4	1.5
22	3	0.4	0.71	0.66	0.1	0.65	2.59	0.03	0.4	8	1.33
23	23	0.4	0.67	0.34	0.27	1.17	5.68	0.05	0.47	31	1.29
24	13	0.4	0.8	0.69	0.33	0.82	1.9	0.05	0.4	6	1.46
25	12	0.29	0.79	0.53	0.36	1.38	2.4	0.06	0.36	12	1.28
26	4	0.4	0.75	0.61	0.16	0.85	2.84	0.05	0.4	7	1.42
27	18	0.36	0.68	0.65	0.34	1.29	2.81	0.06	0.46	10	1.69
28	12	0.38	0.72	0.61	0.23	0.92	2.66	0.04	0.36	11	1.5
29	17	0.29	0.74	0.39	0.47	1.67	2.08	0.07	0.52	12	1.26
30	9	0.36	0.76	0.59	0.461	1.73	1.59	0.1	0.44	6	1.37
31	20	0.38	0.87	0.71	0.52	2.05	2.34	0.07	0.45	13	1.44
32	11	0.28	0.84	0.51	0.36	1.31	2.38	0.06	0.38	11	1.23
33	3	0.41	0.7	0.45	0.12	0.98	2.08	0.04	0.31	6	1.41
34	20	0.43	0.72	0.46	0.5	1.85	2.35	0.09	0.6	12	1.4
35	26	0.28	0.8	0.52	0.43	1.63	3.19	0.07	0.41	16	1.23
36	6	0.25	0.8	0.48	0.26	1.04	2.9	0.06	0.25	8	1.17
37	18	0.3	0.63	0.38	0.17	0.59	2.11	0.03	0.32	6	1.29
38	23	0.34	0.8	0.62	0.43	1.58	2.34	0.06	0.55	15	1.31
39	38	0.38	0.69	0.6	0.52	1.89	3.14	0.09	0.64	15	1.39
40	15	0.36	0.65	0.47	0.31	1.22	3.09	0.06	0.48	10	1.37
41	8	0.68	0.64	0.44	0.25	1.06	2.51	0.04	0.32	10	1.56
42	0	0.29	0.68	0.49	0	0.55	2.62	0.02	0.29	0	1.33
43	13	0.33	0.74	0.47	0.45	1.1	3.5	0.04	0.42	12	1.42
44	18	0.23	0.84	0.56	0.5	1.16	2.76	0.04	0.38	13	1.2
45	35	0.27	0.79	0.44	0.37	0.94	9.5	0.04	0.43	28	1.15

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Continue Table A-2.5

No.	DEL	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
46	19	0.27	0.64	0.54	0.38	0.95	2.45	0.07	0.54	9.5	1.37
47	12	0.36	0.64	0.42	0.47	1	2.59	0.04	0.41	7	1.42
48	0	0.26	0.59	0.4	0.02	0.37	2.6	0.02	0.3	1	1.29
49	9	0.37	0.65	0.55	0.22	0.7	3.11	0.03	0.31	5.5	1.5
50	12	0.4	0.56	0.36	0.47	0.79	2.59	0.05	0.45	6.5	1.57
51	28	0.44	0.73	0.56	0.57	1.16	3.31	0.05	0.37	10.5	1.52
52	14	0.34	0.76	0.58	0.23	0.55	3.26	0.03	0.56	7.5	1.35
53	17	0.31	0.66	0.38	0.3	0.72	3.2	0.03	0.36	8.5	1.38
54	7	0.34	0.69	0.46	0.2	0.63	3.54	0.04	0.3	6.5	1.42
55	13	0.39	0.74	0.6	0.44	0.68	2.69	0.05	0.48	5	1.43
56	4	0.28	0.58	0.51	0.24	0.73	2.8	0.06	0.57	6.5	1.39
57	9	0.37	0.84	0.71	0.27	0.85	3.41	0.04	0.36	7.5	1.33
58	12	0.37	0.82	0.47	0.34	0.74	2.95	0.06	0.5	6.5	1.33
59	6	0.38	0.76	0.59	0.15	0.49	2.9	0.04	0.4	3.5	1.39
60	0	0.47	0.62	0.57	0.13	0.34	2.57	0.02	0.28	1.5	1.5
61	11	0.37	0.38	0.29	0.32	0.6	2.18	0.04	0.42	3.5	1.5
62	11	0.37	0.38	0.29	0.35	0.62	2.18	0.02	0.23	5	1.5
63	6	0.4	0.7	0.66	6.31	0.46	2.59	0.03	0.35	3	1.33
64	33	0.4	0.67	0.34	0.18	0.6	5.68	0.04	0.39	10.5	1.29
65	8	0.4	0.8	0.69	0.49	0.81	1.9	0.06	0.45	6	1.46
66	20	0.29	0.79	0.53	0.53	1.05	2.04	0.06	0.42	7.5	1.28
67	17	0.4	0.75	0.61	0.46	0.96	2.84	0.05	0.42	11.5	1.42
68	6	0.36	0.68	0.65	0.25	0.64	2.81	0.04	0.32	5	1.69
69	16	0.38	0.72	0.61	0.37	0.85	2.66	0.06	0.49	5.5	1.5
70	8	0.29	0.74	0.39	0.3	0.7	2.08	0.04	0.35	3	1.26
71	20	0.36	0.76	0.59	0.98	1.77	1.59	0.13	0.58	6.5	1.37
72	44	0.38	0.87	0.717	1.13	2.56	2.34	0.1	0.65	13	1.44
73	18	0.28	0.84	0.51	0.73	1.39	2.38	0.09	0.53	9	1.23
74	15	0.41	0.7	0.45	0.47	1	2.08	0.05	0.42	7	1.4
75	23	0.43	0.72	0.46	0.66	1.24	2.35	0.07	0.43	7	1.47
76	25	0.28	0.8	0.52	0.65	1.32	3.19	0.09	0.55	10	1.23
77	16	0.25	0.8	0.48	0.68	1.13	2.9	0.1	0.38	7.5	1.17
78	9	0.3	0.63	0.38	0.32	0.68	2.11	0.04	0.49	3.5	1.29
79	7	0.34	0.8	0.62	0.32	0.63	2.34	0.02	0.22	5.5	1.31
80	15	0.38	0.69	0.6	0.4	0.71	3.14	0.03	0.24	5.5	1.39
81	15	0.36	0.65	0.47	0.31	1.22	3.09	0.06	0.48	10	1.37
82	19	0.68	0.64	0.44	0.43	1.6	2.51	0.06	0.48	12	1.56
83	7	0.29	0.68	0.49	0.1	0.53	2.62	0.03	0.34	2.33	1.33
84	4	0.33	0.74	0.47	0.18	0.6	3.5	0.02	0.27	4.66	1.42
85	22	0.27	0.79	0.44	0.27	0.64	9.5	0.03	0.37	13	1.15
86	5	0.23	0.84	0.56	0.22	0.61	2.76	0.02	0.25	3.66	1.2
87	14	0.36	0.64	0.42	0.46	0.84	2.59	0.04	0.35	7.66	1.428
88	11	0.27	0.64	0.54	0.43	0.72	2.45	0.04	0.35	5.66	1.37
89	15	0.37	0.65	0.55	0.44	0.65	3.11	0.03	0.35	5.66	1.37
90	0	0.26	0.59	0.4	0.33	0.64	2.6	0.03	0.32	7	1.5

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Continue Table A-2.5

No.	DEL	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
91	45	0.44	0.73	0.56	1.39	1.58	3.31	0.07	0.47	8.33	1.29
92	6	0.4	0.56	0.36	0.23	0.46	2.59	0.03	0.36	2	1.57
93	9	0.31	0.66	0.38	0.15	0.61	3.2	0.03	0.37	3	1.38
94	20	0.34	0.76	0.58	0.36	0.67	3.26	0.04	0.6	8.33	1.35
95	0	0.39	0.74	0.6	0	0.5	2.69	0.02	0.23	2	1.43
96	15	0.34	0.69	0.46	0.61	0.94	3.54	0.05	0.34	11.3	1.42
97	30	0.37	0.84	0.71	0.58	1.03	3.41	0.05	0.42	8	1.33
98	0	0.28	0.58	0.51	0	0.39	2.8	0.02	0.26	0	1.39
99	20	0.37	0.82	0.47	1	1.2	2.95	0.07	0.53	9.33	1.33
100	4	0.38	0.76	0.59	0.33	0.54	2.9	0.04	0.36	3.33	1.39
101	3	0.47	0.62	0.57	0.03	0.4	2.57	0.03	0.3	1	1.5
102	12	0.37	0.38	0.29	0.57	0.55	2.18	0.03	0.36	2.66	1.5
103	10	0.37	0.38	0.29	0.54	0.63	2.18	0.04	0.42	3.33	1.5
104	6	0.4	0.71	0.66	0.13	0.49	2.59	0.03	0.41	1	1.33
105	31	0.4	0.67	0.34	0.48	0.68	5.68	0.05	0.4	10.3	1.29
106	5	0.4	0.8	0.69	0.39	0.51	1.9	0.04	0.3	3.66	1.46
107	24	0.29	0.79	0.53	0.89	1.12	2.4	0.07	0.44	7	1.28
108	3	0.4	0.75	0.61	8.11	0.5	2.84	0.03	0.3	2	1.42
109	13	0.36	0.68	0.65	0.61	0.93	2.81	0.05	0.4	7.33	1.69
110	6	0.38	0.72	0.61	0.22	0.67	2.66	0.04	0.41	4	1.5
111	15	0.29	0.74	0.39	0.65	0.89	2.08	0.07	0.51	5	1.26
112	9	0.36	0.76	0.59	1.08	1.32	1.59	0.1	0.46	5.33	1.37
113	15	0.38	0.87	0.71	0.53	1.11	2.34	0.06	0.41	6.33	1.44
114	18	0.28	0.84	0.51	0.83	1.16	2.38	0.07	0.46	8	1.23
115	12	0.41	0.7	0.45	0.52	0.93	2.08	0.06	0.52	5	1.41
116	33	0.43	0.72	0.46	1.3	1.78	2.35	0.09	0.59	11	1.47
117	21	0.28	0.8	0.52	0.78	0.92	3.19	0.06	0.42	6.33	1.23
118	21	0.25	0.8	0.48	1.28	1.35	2.9	0.12	0.47	9	1.17
119	5	0.3	0.63	0.38	0.53	0.56	2.11	0.02	0.29	5.33	1.29
120	6	0.34	0.8	0.62	0.45	0.62	2.3	0.04	0.36	3.33	1.31
121	37	0.38	0.69	0.6	1.28	1.54	3.14	0.07	0.54	13.7	1.39
122	14	0.36	0.65	0.47	0.43	0.66	3.09	0.04	0.38	5.66	1.37
123	11	0.68	0.64	0.44	0.44	0.57	2.51	0.04	0.35	3.33	1.562
124	6	0.23	0.84	0.56	0.15	0.56	2.76	0.02	0.24	2.66	1.2
125	0	0.29	0.68	0.49	0	0.55	2.62	0.02	0.29	0	1.33
126	8	0.34	0.8	0.62	0.25	1.05	2.34	0.04	0.36	8	1.31
127	15	0.38	0.69	0.6	0.4	0.71	3.14	0.03	0.24	5.5	1.39
128	7	0.4	0.56	0.36	0.3	0.5	2.59	0.05	0.46	2.33	1.57
129	3	0.47	0.62	0.57	0.03	0.4	2.57	0.03	0.3	1	1.5
130	15	0.34	0.69	0.46	0.79	1.05	3.54	0.05	0.38	12.7	1.42
131	23	0.37	0.65	0.55	0.38	0.88	3.11	0.03	0.39	9.5	1.5
132	29	0.34	0.69	0.46	0.56	1.04	3.54	0.06	0.46	9.5	1.42
133	12	0.33	0.74	0.47	0.39	0.76	3.5	0.03	0.37	6.66	1.42
134	9	0.38	0.76	0.59	0.24	0.6	2.9	0.04	0.45	5	1.39
135	14	0.27	0.64	0.54	0.68	0.9	2.45	0.05	0.44	7.33	1.37

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Table A-2.6: Delay (Del) , and the ten summary measures (B1 ... B10) of the 135 Testnetworks scheduled by LFT.

No.	DEL	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
1	2	0.29	0.68	0.49	0.01	0.65	2.62	0.03	0.36	2	1.33
2	21	0.33	0.74	0.47	0.31	1.32	3.5	0.04	0.4	18	1.42
3	22	0.23	0.84	0.56	0.28	1.28	2.76	0.04	0.4	17	1.2
4	12	0.27	0.79	0.44	0.02	0.77	9.5	0.03	0.3	14	1.15
5	7	0.27	0.64	0.54	0.17	0.81	2.45	0.05	0.39	7	1.37
6	5	0.36	0.64	0.42	0.17	0.84	2.59	0.03	0.25	8	1.42
7	5	0.26	0.59	0.4	0.02	0.55	2.61	0.02	0.3	2	1.29
8	1	0.37	0.65	0.55	0.02	0.53	3.11	0.02	0.23	2	1.5
9	2	0.4	0.56	0.36	0.02	0.46	2.59	0.02	0.24	2	1.57
10	20	0.44	0.73	0.56	0.29	1.28	3.31	0.04	0.29	13	1.52
11	0	0.34	0.76	0.58	0	0.55	3.26	0.02	0.33	0	1.35
12	2	0.31	0.66	0.38	1.99	0.61	3.2	0.02	0.23	2	1.38
13	16	0.34	0.69	0.46	0.25	0.96	3.54	0.05	0.37	11	1.42
14	7	0.39	0.74	0.6	0.13	0.82	2.69	0.04	0.35	7	1.43
15	3	0.28	0.58	0.51	4.58	0.75	2.8	0.04	0.4	6	1.39
16	26	0.37	0.84	0.71	0.29	1.29	3.41	0.05	0.4	13	1.33
17	10	0.37	0.82	0.47	0.18	1	2.95	0.04	0.35	12	1.33
18	12	0.38	0.76	0.59	0.18	1.06	2.09	0.05	0.49	13	1.39
19	6	0.47	0.62	0.57	0.13	0.65	2.57	0.03	0.36	3	1.5
20	16	0.32	0.77	0.54	0.35	1.2	3.07	0.04	0.34	14	1.27
21	10	0.37	0.38	0.29	0.28	1.03	2.18	0.04	0.4	4	1.5
22	9	0.4	0.71	0.66	0.1	0.65	2.59	0.03	0.4	8	1.33
23	28	0.4	0.67	0.34	0.27	1.17	5.68	0.05	0.47	31	1.29
24	9	0.4	0.8	0.69	0.33	0.82	1.9	0.05	0.4	6	1.46
25	17	0.29	0.79	0.53	0.36	1.38	2.4	0.06	0.36	12	1.28
26	9	0.4	0.75	0.61	0.16	0.85	2.84	0.05	0.4	7	1.42
27	22	0.36	0.68	0.65	0.34	1.29	2.81	0.06	0.46	10	1.69
28	10	0.38	0.72	0.61	0.23	0.92	2.66	0.04	0.36	11	1.5
29	24	0.29	0.74	0.39	0.47	1.67	2.08	0.07	0.52	12	1.26
30	12	0.36	0.76	0.59	0.461	1.73	1.59	0.1	0.44	6	1.37
31	23	0.38	0.87	0.71	0.52	2.05	2.34	0.07	0.45	13	1.44
32	12	0.28	0.84	0.51	0.36	1.31	2.38	0.06	0.38	11	1.23
33	5	0.41	0.7	0.45	0.12	0.98	2.08	0.04	0.31	6	1.41
34	19	0.43	0.72	0.46	0.5	1.85	2.35	0.09	0.6	12	1.4
35	25	0.28	0.8	0.52	0.43	1.63	3.19	0.07	0.41	16	1.23
36	8	0.25	0.8	0.48	0.26	1.04	2.9	0.06	0.25	8	1.17
37	21	0.3	0.63	0.38	0.17	0.59	2.11	0.03	0.32	6	1.29
38	24	0.34	0.8	0.62	0.43	1.58	2.34	0.06	0.55	15	1.31
39	35	0.38	0.69	0.6	0.52	1.89	3.14	0.09	0.64	15	1.39
40	18	0.36	0.65	0.47	0.31	1.22	3.09	0.06	0.48	10	1.37
41	10	0.68	0.64	0.44	0.25	1.06	2.51	0.04	0.32	10	1.56
42	0	0.29	0.68	0.49	0	0.55	2.62	0.02	0.29	0	1.33
43	17	0.33	0.74	0.47	0.45	1.1	3.5	0.04	0.42	12	1.42
44	17	0.23	0.84	0.56	0.5	1.16	2.76	0.04	0.38	13	1.2
45	36	0.27	0.79	0.44	0.37	0.94	9.5	0.04	0.43	28	1.15

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Continue Table A-2.6

No.	DEL	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
91	61	0.44	0.73	0.56	1.39	1.58	3.31	0.07	0.47	8.33	1.29
92	6	0.4	0.56	0.36	0.23	0.46	2.59	0.03	0.36	2	1.57
93	5	0.31	0.66	0.38	0.15	0.61	3.2	0.03	0.37	3	1.38
94	18	0.34	0.76	0.58	0.36	0.67	3.26	0.04	0.6	8.33	1.35
95	0	0.39	0.74	0.6	0	0.5	2.69	0.02	0.23	2	1.43
96	19	0.34	0.69	0.46	0.61	0.94	3.54	0.05	0.34	11.3	1.42
97	34	0.37	0.84	0.71	0.58	1.03	3.41	0.05	0.42	8	1.33
98	0	0.28	0.58	0.51	0	0.39	2.8	0.02	0.26	0	1.39
99	22	0.37	0.82	0.47	1	1.2	2.95	0.07	0.53	9.33	1.33
100	11	0.38	0.76	0.59	0.33	0.54	2.9	0.04	0.36	3.33	1.39
101	3	0.47	0.62	0.57	0.03	0.4	2.57	0.03	0.3	1	1.5
102	10	0.37	0.38	0.29	0.57	0.55	2.18	0.03	0.36	2.66	1.5
103	12	0.37	0.38	0.29	0.54	0.63	2.18	0.04	0.42	3.33	1.5
104	6	0.4	0.71	0.66	0.13	0.49	2.59	0.03	0.41	1	1.33
105	25	0.4	0.67	0.34	0.48	0.68	5.68	0.05	0.4	10.3	1.29
106	4	0.4	0.8	0.69	0.39	0.51	1.9	0.04	0.3	3.66	1.46
107	29	0.29	0.79	0.53	0.89	1.12	2.4	0.07	0.44	7	1.28
108	3	0.4	0.75	0.61	8.11	0.5	2.84	0.03	0.3	2	1.42
109	19	0.36	0.68	0.65	0.61	0.93	2.81	0.05	0.4	7.33	1.69
110	5	0.38	0.72	0.61	0.22	0.67	2.66	0.04	0.41	4	1.5
111	22	0.29	0.74	0.39	0.65	0.89	2.08	0.07	0.51	5	1.26
112	10	0.36	0.76	0.59	1.08	1.32	1.59	0.1	0.46	5.33	1.37
113	16	0.38	0.87	0.71	0.53	1.11	2.34	0.06	0.41	6.33	1.44
114	21	0.28	0.84	0.51	0.83	1.16	2.38	0.07	0.46	8	1.23
115	14	0.41	0.7	0.45	0.52	0.93	2.08	0.06	0.52	5	1.41
116	35	0.43	0.72	0.46	1.3	1.78	2.35	0.09	0.59	11	1.47
117	21	0.28	0.8	0.52	0.78	0.92	3.19	0.06	0.42	6.33	1.23
118	25	0.25	0.8	0.48	1.28	1.35	2.9	0.12	0.47	9	1.17
119	8	0.3	0.63	0.38	0.53	0.56	2.11	0.02	0.29	5.33	1.29
120	9	0.34	0.8	0.62	0.45	0.62	2.3	0.04	0.36	3.33	1.31
121	38	0.38	0.69	0.6	1.28	1.54	3.14	0.07	0.54	13.7	1.39
122	14	0.36	0.65	0.47	0.43	0.66	3.09	0.04	0.38	5.66	1.37
123	10	0.68	0.64	0.44	0.44	0.57	2.51	0.04	0.35	3.33	1.562
124	7	0.23	0.84	0.56	0.15	0.56	2.76	0.02	0.24	2.66	1.2
125	0	0.29	0.68	0.49	0	0.55	2.62	0.02	0.29	0	1.33
126	8	0.34	0.8	0.62	0.25	1.05	2.34	0.04	0.36	8	1.31
127	19	0.38	0.69	0.6	0.4	0.71	3.14	0.03	0.24	5.5	1.39
128	6	0.4	0.56	0.36	0.3	0.5	2.59	0.05	0.46	2.33	1.57
129	3	0.47	0.62	0.57	0.03	0.4	2.57	0.03	0.3	1	1.5
130	18	0.34	0.69	0.46	0.79	1.05	3.54	0.05	0.38	12.7	1.42
131	17	0.37	0.65	0.55	0.38	0.88	3.11	0.03	0.39	9.5	1.5
132	29	0.34	0.69	0.46	0.56	1.04	3.54	0.06	0.46	9.5	1.42
133	13	0.33	0.74	0.47	0.39	0.76	3.5	0.03	0.37	6.66	1.42
134	18	0.38	0.76	0.59	0.24	0.6	2.9	0.04	0.45	5	1.39
135	16	0.27	0.64	0.54	0.68	0.9	2.45	0.05	0.44	7.33	1.37

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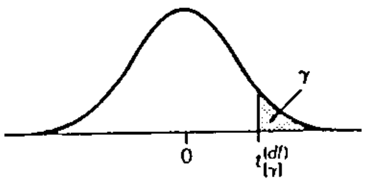
Critical values of *t*



df	$t^{(df)}_{[.40]}$	$t^{(df)}_{[.30]}$	$t^{(df)}_{[.20]}$	$t^{(df)}_{[.15]}$	$t^{(df)}_{[.10]}$	$t^{(df)}_{[.05]}$	$t^{(df)}_{[.025]}$
1	0.325	0.727	1.376	1.963	3.078	6.314	12.706
2	0.289	0.617	1.061	1.386	1.886	2.920	4.303
3	0.277	0.584	0.978	1.250	1.638	2.353	3.182
4	0.271	0.569	0.941	1.190	1.533	2.132	2.776
5	0.267	0.559	0.920	1.156	1.476	2.015	2.571
6	0.265	0.553	0.906	1.134	1.440	1.943	2.447
7	0.263	0.549	0.896	1.119	1.415	1.895	2.365
8	0.262	0.546	0.889	1.108	1.397	1.860	2.306
9	0.261	0.543	0.883	1.100	1.383	1.833	2.262
10	0.260	0.542	0.879	1.093	1.372	1.812	2.228
11	0.260	0.540	0.876	1.088	1.363	1.796	2.201
12	0.259	0.539	0.873	1.083	1.356	1.782	2.179
13	0.259	0.537	0.870	1.079	1.350	1.771	2.160
14	0.258	0.537	0.868	1.076	1.345	1.761	2.145
15	0.258	0.536	0.866	1.074	1.341	1.753	2.131
16	0.258	0.535	0.865	1.071	1.337	1.746	2.120
17	0.257	0.534	0.863	1.069	1.333	1.740	2.110
18	0.257	0.534	0.862	1.067	1.330	1.734	2.101
19	0.257	0.533	0.861	1.066	1.328	1.729	2.093
20	0.257	0.533	0.860	1.064	1.325	1.725	2.086
21	0.257	0.532	0.859	1.063	1.323	1.721	2.080
22	0.256	0.532	0.858	1.061	1.321	1.717	2.074
23	0.256	0.532	0.858	1.060	1.319	1.714	2.069
24	0.256	0.531	0.857	1.059	1.318	1.711	2.064
25	0.256	0.531	0.856	1.058	1.316	1.708	2.060
26	0.256	0.531	0.856	1.058	1.315	1.706	2.056
27	0.256	0.531	0.855	1.057	1.314	1.703	2.052
28	0.256	0.530	0.855	1.056	1.313	1.701	2.048
29	0.256	0.530	0.854	1.055	1.311	1.699	2.045
30	0.256	0.530	0.854	1.055	1.310	1.697	2.042
40	0.255	0.529	0.851	1.050	1.303	1.684	2.021
60	0.254	0.527	0.848	1.045	1.296	1.671	2.000
120	0.254	0.526	0.845	1.041	1.289	1.658	1.980
∞	0.253	0.524	0.842	1.036	1.282	1.645	1.960

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df	$t^{(df)}_{(.02)}$	$t^{(df)}_{(.015)}$	$t^{(df)}_{(.01)}$	$t^{(df)}_{(.0075)}$	$t^{(df)}_{(.005)}$	$t^{(df)}_{(.0025)}$	$t^{(df)}_{(.0005)}$
1	15.895	21.205	31.821	42.434	63.657	127.322	636.590
2	4.849	5.643	6.965	8.073	9.925	14.089	31.598
3	3.482	3.896	4.541	5.047	5.841	7.453	12.924
4	2.999	3.298	3.747	4.088	4.604	5.598	8.610
5	2.757	3.003	3.365	3.634	4.032	4.773	6.869
6	2.612	2.829	3.143	3.372	3.707	4.317	5.959
7	2.517	2.715	2.998	3.203	3.499	4.029	5.408
8	2.449	2.634	2.896	3.085	3.355	3.833	5.041
9	2.398	2.574	2.821	2.998	3.250	3.690	4.781
10	2.359	2.527	2.764	2.932	3.169	3.581	4.587
11	2.328	2.491	2.718	2.879	3.106	3.497	4.437
12	2.303	2.461	2.681	2.836	3.055	3.428	4.318
13	2.282	2.436	2.650	2.801	3.012	3.372	4.221
14	2.264	2.415	2.624	2.771	2.977	3.326	4.140
15	2.249	2.397	2.602	2.746	2.947	3.286	4.073
16	2.235	2.382	2.583	2.724	2.921	3.252	4.015
17	2.224	2.368	2.567	2.706	2.898	3.222	3.965
18	2.214	2.356	2.552	2.689	2.878	3.197	3.922
19	2.205	2.346	2.539	2.674	2.861	3.174	3.883
20	2.197	2.336	2.528	2.661	2.845	3.153	3.849
21	2.189	2.328	2.518	2.649	2.831	3.135	3.819
22	2.183	2.320	2.508	2.639	2.819	3.119	3.792
23	2.177	2.313	2.500	2.629	2.807	3.104	3.768
24	2.172	2.307	2.492	2.620	2.797	3.091	3.745
25	2.167	2.301	2.485	2.612	2.787	3.078	3.725
26	2.162	2.296	2.479	2.605	2.779	3.067	3.707
27	2.158	2.291	2.473	2.598	2.771	3.057	3.690
28	2.154	2.286	2.467	2.592	2.763	3.047	3.674
29	2.150	2.282	2.462	2.586	2.756	3.038	3.659
30	2.147	2.278	2.457	2.581	2.750	3.030	3.646
40	2.123	2.250	2.423	2.542	2.704	2.971	3.551
60	2.099	2.223	2.390	2.504	2.660	2.915	3.460
120	2.076	2.196	2.358	2.468	2.617	2.860	3.373
∞	2.054	2.170	2.326	2.432	2.576	2.807	3.291

Source: Reprinted from Neter, J., W. Wasserman, and M. H. Kutner, *Applied Linear Statistical Models*. 2nd ed. Homewood, Ill.: Richard Irwin, 1985.

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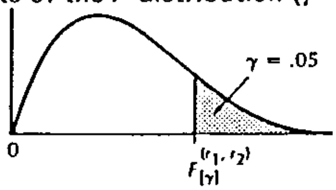
Percentage points of the F-distribution (γ = .05)



Denominator degrees of freedom, r_2	Numerator degrees of freedom, r_1								
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
1	161.4	199.5	215.7	224.6	230.2	234.0	236.8	238.9	240.5
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04
120	3.92	3.07	2.68	2.45	2.29	2.17	2.09	2.02	1.96
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88

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Denominator degrees of freedom, r_2	Numerator degrees of freedom, r_1									
	10	12	15	20	24	30	40	60	120	∞
1	241.9	243.9	245.9	248.0	249.1	250.1	251.1	252.2	253.3	254.3
2	19.40	19.41	19.43	19.45	19.45	19.46	19.47	19.48	19.49	19.50
3	8.79	8.74	8.70	8.66	8.64	8.62	8.59	8.57	8.55	8.53
4	5.96	5.91	5.86	5.80	5.77	5.75	5.72	5.69	5.66	5.63
5	4.74	4.68	4.62	4.56	4.53	4.50	4.46	4.43	4.40	4.36
6	4.06	4.00	3.94	3.87	3.84	3.81	3.77	3.74	3.70	3.67
7	3.64	3.57	3.51	3.44	3.41	3.38	3.34	3.30	3.27	3.23
8	3.35	3.28	3.22	3.15	3.12	3.08	3.04	3.01	2.97	2.93
9	3.14	3.07	3.01	2.94	2.90	2.86	2.83	2.79	2.75	2.71
10	2.98	2.91	2.85	2.77	2.74	2.70	2.66	2.62	2.58	2.54
11	2.85	2.79	2.72	2.65	2.61	2.57	2.53	2.49	2.45	2.40
12	2.75	2.69	2.62	2.54	2.51	2.47	2.43	2.38	2.34	2.30
13	2.67	2.60	2.53	2.46	2.42	2.38	2.34	2.30	2.25	2.21
14	2.60	2.53	2.46	2.39	2.35	2.31	2.27	2.22	2.18	2.13
15	2.54	2.48	2.40	2.33	2.29	2.25	2.20	2.16	2.11	2.07
16	2.49	2.42	2.35	2.28	2.24	2.19	2.15	2.11	2.06	2.01
17	2.45	2.38	2.31	2.23	2.19	2.15	2.10	2.06	2.01	1.96
18	2.41	2.34	2.27	2.19	2.15	2.11	2.06	2.02	1.97	1.92
19	2.38	2.31	2.23	2.16	2.11	2.07	2.03	1.98	1.93	1.88
20	2.35	2.28	2.20	2.12	2.08	2.04	1.99	1.95	1.90	1.84
21	2.32	2.25	2.18	2.10	2.05	2.01	1.96	1.92	1.87	1.81
22	2.30	2.23	2.15	2.07	2.03	1.98	1.94	1.89	1.84	1.78
23	2.27	2.20	2.13	2.05	2.01	1.96	1.91	1.86	1.81	1.76
24	2.25	2.18	2.11	2.03	1.98	1.94	1.89	1.84	1.79	1.73
25	2.24	2.16	2.09	2.01	1.96	1.92	1.87	1.82	1.77	1.71
26	2.22	2.15	2.07	1.99	1.95	1.90	1.85	1.80	1.75	1.69
27	2.20	2.13	2.06	1.97	1.93	1.88	1.84	1.79	1.73	1.67
28	2.19	2.12	2.04	1.96	1.91	1.87	1.82	1.77	1.71	1.65
29	2.18	2.10	2.03	1.94	1.90	1.85	1.81	1.75	1.70	1.64
30	2.16	2.09	2.01	1.93	1.89	1.84	1.79	1.74	1.68	1.62
40	2.08	2.00	1.92	1.84	1.79	1.74	1.69	1.64	1.58	1.51
60	1.99	1.92	1.84	1.75	1.70	1.65	1.59	1.53	1.47	1.39
120	1.91	1.83	1.75	1.66	1.61	1.55	1.50	1.43	1.35	1.25
∞	1.83	1.75	1.67	1.57	1.52	1.46	1.39	1.32	1.22	1.00

Source: From "Tables of Percentage Points of the Inverted Beta (F)-Distribution," by Maxine Merrington and Catherine M. Thompson, *Biometrika* 33 (1943), 73-88.

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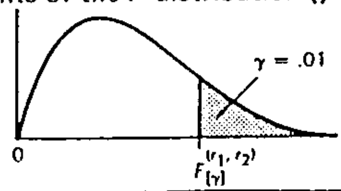
Percentage points of the F-distribution (γ = .01)



Denominator degrees of freedom, r_2	*Numerator degrees of freedom, r_1*								
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
1	4052	4999.5	5403	5625	5764	5859	5928	5982	6022
2	98.50	99.00	99.17	99.25	99.30	99.33	99.36	99.37	99.39
3	34.12	30.82	29.46	28.71	28.24	27.91	27.67	27.49	27.35
4	21.20	18.00	16.69	15.98	15.52	15.21	14.98	14.80	14.66
5	16.26	13.27	12.06	11.39	10.97	10.67	10.46	10.29	10.16
6	13.75	10.92	9.78	9.15	8.75	8.47	8.26	8.10	7.98
7	12.25	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.72
8	11.26	8.65	7.59	7.01	6.63	6.37	6.18	6.03	5.91
9	10.56	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.35
10	10.04	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.94
11	9.65	7.21	6.22	5.67	5.32	5.07	4.89	4.74	4.63
12	9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.39
13	9.07	6.70	5.74	5.21	4.86	4.62	4.44	4.30	4.19
14	8.86	6.51	5.56	5.04	4.69	4.46	4.28	4.14	4.03
15	8.68	6.36	5.42	4.89	4.56	4.32	4.14	4.00	3.89
16	8.53	6.23	5.29	4.77	4.44	4.20	4.03	3.89	3.78
17	8.40	6.11	5.18	4.67	4.34	4.10	3.93	3.79	3.68
18	8.29	6.01	5.09	4.58	4.25	4.01	3.84	3.71	3.60
19	8.18	5.93	5.01	4.50	4.17	3.94	3.77	3.63	3.52
20	8.10	5.85	4.94	4.43	4.10	3.87	3.70	3.56	3.46
21	8.02	5.78	4.87	4.37	4.04	3.81	3.64	3.51	3.40
22	7.95	5.72	4.82	4.31	3.99	3.76	3.59	3.45	3.35
23	7.88	5.66	4.76	4.26	3.94	3.71	3.54	3.41	3.30
24	7.82	5.61	4.72	4.22	3.90	3.67	3.50	3.36	3.26
25	7.77	5.57	4.68	4.18	3.85	3.63	3.46	3.32	3.22
26	7.72	5.53	4.64	4.14	3.82	3.59	3.42	3.29	3.18
27	7.68	5.49	4.60	4.11	3.78	3.56	3.39	3.26	3.15
28	7.64	5.45	4.57	4.07	3.75	3.53	3.36	3.23	3.12
29	7.60	5.42	4.54	4.04	3.73	3.50	3.33	3.20	3.09
30	7.56	5.39	4.51	4.02	3.70	3.47	3.30	3.17	3.07
40	7.31	5.18	4.31	3.83	3.51	3.29	3.12	2.99	2.89
60	7.08	4.98	4.13	3.65	3.34	3.12	2.95	2.82	2.72
120	6.85	4.79	3.95	3.48	3.17	2.96	2.79	2.66	2.50
∞	6.63	4.61	3.78	3.32	3.02	2.80	2.64	2.51	2.41

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Denominator degrees of freedom, r_2	*Numerator degrees of freedom, r_1*									
	10	*12*	*15*	*20*	*24*	*30*	*40*	*60*	*120*	*∞*
1	6056	6106	6157	6209	6235	6261	6287	6313	6339	6366
2	99.40	99.42	99.43	99.45	99.46	99.47	99.47	99.48	99.49	99.50
3	27.23	27.05	26.87	26.69	26.60	26.50	26.41	26.32	26.22	26.13
4	14.55	14.37	14.20	14.02	13.93	13.84	13.75	13.65	13.56	13.46
5	10.05	9.89	9.72	9.55	9.47	9.38	9.29	9.20	9.11	9.02
6	7.87	7.72	7.56	7.40	7.31	7.23	7.14	7.06	6.97	6.88
7	6.62	6.47	6.31	6.16	6.07	5.99	5.91	5.82	5.74	5.65
8	5.81	5.67	5.52	5.36	5.28	5.20	5.12	5.03	4.95	4.86
9	5.26	5.11	4.96	4.81	4.73	4.65	4.57	4.48	4.40	4.31
10	4.85	4.71	4.56	4.41	4.33	4.25	4.17	4.08	4.00	3.91
11	4.54	4.40	4.25	4.10	4.02	3.94	3.86	3.78	3.69	3.60
12	4.30	4.16	4.01	3.86	3.78	3.70	3.62	3.54	3.45	3.36
13	4.10	3.96	3.82	3.66	3.59	3.51	3.43	3.34	3.25	3.17
14	3.94	3.80	3.66	3.51	3.43	3.35	3.27	3.18	3.09	3.00
15	3.80	3.67	3.52	3.37	3.29	3.21	3.13	3.05	2.96	2.87
16	3.69	3.55	3.41	3.26	3.18	3.10	3.02	2.93	2.84	2.75
17	3.59	3.46	3.31	3.16	3.08	3.00	2.92	2.83	2.75	2.65
18	3.51	3.37	3.23	3.08	3.00	2.92	2.84	2.75	2.66	2.57
19	3.43	3.30	3.15	3.00	2.92	2.84	2.76	2.67	2.58	2.49
20	3.37	3.23	3.09	2.94	2.86	2.78	2.69	2.61	2.52	2.42
21	3.31	3.17	3.03	2.88	2.80	2.72	2.64	2.55	2.46	2.36
22	3.26	3.12	2.98	2.83	2.75	2.67	2.58	2.50	2.40	2.31
23	3.21	3.07	2.93	2.78	2.70	2.62	2.54	2.45	2.35	2.26
24	3.17	3.03	2.89	2.74	2.66	2.58	2.49	2.40	2.31	2.21
25	3.13	2.99	2.85	2.70	2.62	2.54	2.45	2.36	2.27	2.17
26	3.09	2.96	2.81	2.66	2.58	2.50	2.42	2.33	2.23	2.13
27	3.06	2.93	2.78	2.63	2.55	2.47	2.38	2.29	2.20	2.10
28	3.03	2.90	2.75	2.60	2.52	2.44	2.35	2.26	2.17	2.06
29	3.00	2.87	2.73	2.57	2.49	2.41	2.33	2.23	2.14	2.03
30	2.98	2.84	2.70	2.55	2.47	2.39	2.30	2.21	2.11	2.01
40	2.80	2.66	2.52	2.37	2.29	2.20	2.11	2.02	1.92	1.80
60	2.63	2.50	2.35	2.20	2.12	2.03	1.94	1.84	1.73	1.60
120	2.47	2.34	2.19	2.03	1.95	1.86	1.76	1.66	1.53	1.38
∞	2.32	2.18	2.04	1.88	1.79	1.70	1.59	1.47	1.32	1.00

Source: From "Tables of Percentage Points of the Inverted Beta (*F*)-Distribution," by Maxine Merrington and Catherine M. Thompson, *Biometrika* 33 (1943), 73–88.

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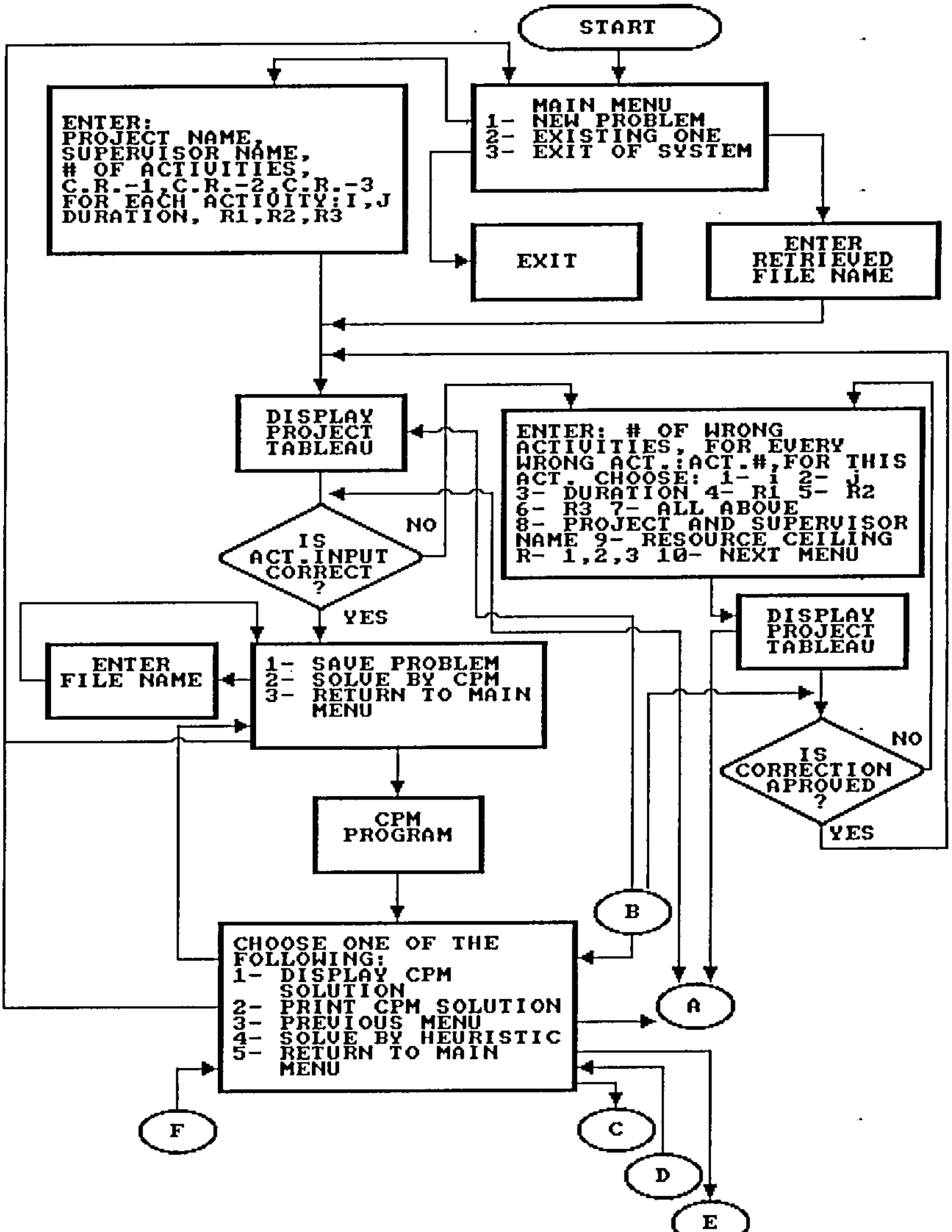

Fig. (4.1) Flowchart of Resource Allocation (ReALL-1)

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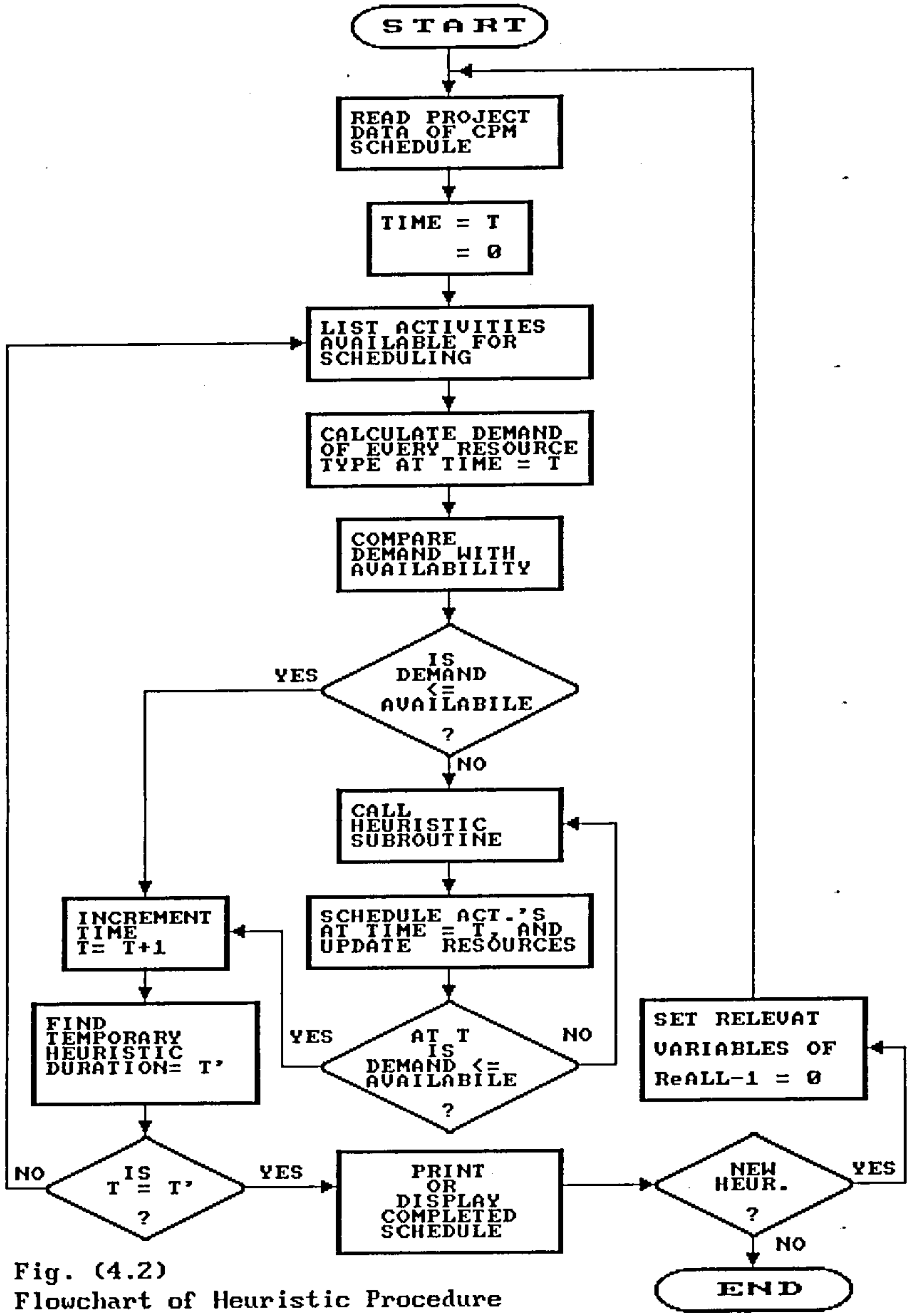

Fig. (4.2)
Flowchart of Heuristic Procedure

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