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ECON INCORPORATED

76-113-1
NINE HUNDRED STATE ROAD
PRINCETON, NEW JERSEY 08540
609 924-8778

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# A METHODOLOGY FOR THE EVALUATION OF PROGRAM COST AND SCHEDULE RISK FOR THE SEASAT PROGRAM

Prepared for

National Aeronautics and Space Administration
Special Programs Division
Office of Applications
Washington, DC

Contract No. NASW-2558

August 31, 1976

## NOTE OF TRANSMITTAL

This report describes a risk evaluation program called RISKNET which can be used to evaluate program cost and schedule risk. This work was performed for the Special Programs Division, Office of Applications, National Aeronautics and Space Administration, under Contract NASW-2558. The purpose of this effort was to demonstrate a methodology, using SEASAT-A data, which could subsequently be used to evaluate the cost and schedule probability distributions for alternative SEASAT follow-on options. The ultimate objective of this work is to provide a methodology which can be used to obtain a quantitative measure of program risk as a function of the technical complexity of the selected SEASAT follow-on program alternatives. The work performed to date indicates that RISKNET can be used for this purpose. Thus, if data in the form described in this report can be obtained in future studies of SEASAT follow-on alternatives, it will be possible to add the additional dimension of cost and schedule risk, in the form of probability distributions for these parameters, to the information available to NASA management for the evaluation of program alternatives.

The work described in this report was performed by Mr. Philip Abram and Ms. Debra Myers.

Prepared By:

Philip Abram

Approved By:

B. P. Miller

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# 1. OVERVIEW OF THE ANALYSIS

SEASAT-A is the first satellite to be launched in the SEASAT program and is currently in the process of being designed and fabricated. The SEASAT-A program consists of the independent activities of several contractors in the development of the launch vehicle, bus, sensor module, and the five major sensors. As the development plan requires many schedule interfaces both within and among the contractors, the total program progress is difficult to accurately monitor and control, and a form of automatic computational assistance such as PERT is often necessary for this purpose.

RISKNET is an interactive computerized project management software package which is designed to analyze the effect of the risk involved in each specific activity on the results of the total program. Both the time and the cost of each distinct activity can be modeled with an uncertainty interval so as to provide the project manager with not only the expected time and cost for the completion of the total program, but also with the expected range of costs corresponding to any desired level of significance.

This document outlines the nature of the SEASAT-A program, discusses the capabilities of RISKNET, and describes the implementation plan of a RISKNET analysis for the development of SEASAT-A.

# 2. SEASAT PROGRAM DESCRIPTION*

## 2.1 Overview of Program

The SEASAT Program provides a base for the use of space platforms for global and local explorations into the dynamics and resources of the ocean, into the effect of ocean on weather and climate, and into the role the ocean plays in ice and coastal processes. The set of sensors which are expected to be included in the operational system have the capability to measure and delineate ocean and weather characteristics, such as wave heights, length and direction, sea-surface wind velocities and directions, temperature, wave length, currents, oil and chemical pollution, upswellings, shoals, ice leads, icebergs, etc. This information can be used in many social and economic applications in creating a better understanding of the ocean and its dynamics as a guide to the better management of the usage of this limited resource. Some of the possible applications of SEASAT are listed in Table 2.1.

The SEASAT program is a first attempt to exploit the broad applicability of both active and passive microwave sensors in conjunction with the more conventional passive infrared sensors. The level of microwave energy backscattered and the shape of the return pulse from the ocean surface are modulated by the winds, waves, temperature, salinity, nutrient and pollution content, current and upwelling motions, rain, surface pressure, and other items which are of interest to the expected application areas. The energy from the surface is similarly modulated

*A complete description of the SEASAT program can be found in Volume II, SEASAT report.

# Table 2.1 Sample SEASAT Application Areas

● PRIMARY
□ SECONDARY

| SEASAT INVESTIGATION POSSIBILITIES | SENSOR TYPES: VISIBLE AND INFRARED RADIOMETER | MICROWAVE RADIOMETER | SHORT PULSE ALTIMETER | LONG PULSE SCATTEROMETER | COHERENT IMAGING RADAR | DOPPLER RADAR | LIDAR | MAJOR AREAS OF ECONOMIC BENEFIT: SHIP/TANKER-ROUTING/PROTECTION | MARINE FISHERIES-OPERATIONS/YIELD MANAGEMENT | OFFSHORE RIGS/STRUCTURES/PORTS-OPERATIONS/PROTECTION | BEACH/SHOAL-PROTECTION/MANAGEMENT | ICE NAVIGATION-ROUTING/MANAGEMENT | COASTAL INDUSTRY/RECREATION-OPERATIONS SCHEDULING/PROTECTION | AGRICULTURE-YIELD MANAGEMENT | POLLUTION-MONITOR/REGULATE | OCEAN MINING/AQUACULTURE-OPERATIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PHYSICAL OCEANOGRAPHY | □ | □ | □ | ● | ● | | □ | | | | | | | | | |
| CAPILLARY/GRAVITY WAVE GENERATION | | □ | □ | ● | ● | | □ | | | □ | □ | | □ | | | □ |
| WAVE PROPAGATION NEAR STORMS | | □ | ● | □ | ● | | □ | | | □ | □ | | □ | | | □ |
| WAVE PROPAGATION AT CONTINENTAL SHELF | | | □ | | ● | | □ | | | □ | □ | | □ | | | □ |
| INTERNAL WAVE PROPAGATION | | | □ | | ● | | □ | | | | | | | | | |
| WAVE FORECAST VERIFICATIONS | | □ | □ | ● | ● | | □ | ● | ● | ● | ● | | □ | | | ● |
| LOCATION/DYNAMICS OF OCEAN CURRENTS | □ | □ | □ | | ● | | □ | ● | ● | | | □ | | | | □ |
| TRANSPORT OF POLLUTANTS/NUTRIENTS | ● | □ | | | ● | | □ | | ● | | | | | | ● | |
| UPWELLING FORECASTS | □ | □ | | ● | ● | | | | ● | | | □ | | | | |
| TSUNAMI PROPAGATION (FORTUITOUS) | | | □ | | | | □ | | | □ | □ | | □ | | | |
| CLIMATE | ● | ● | □ | ● | □ | □ | □ | | | | | | | | | |
| AIR/SEA INTERACTIONS | | ● | □ | ● | □ | | □ | ● | ● | ● | ● | | ● | □ | | □ |
| WIND/CLOUD RELATIONS | ● | ● | | | | | | □ | □ | □ | □ | | □ | □ | | □ |
| WIND/RAIN/TEMPERATURE INTERACTIONS | □ | ● | | ● | | ● | | □ | □ | □ | □ | | □ | □ | | □ |
| SURFACE TEMPERATURE AND STORM GROWTH | □ | ● | □ | ● | □ | | □ | □ | □ | □ | □ | | □ | □ | | □ |
| JET STREAM DEFLECTION | ● | ● | | | | | | □ | □ | □ | □ | | □ | | | |
| SEVERE STORM GENERATION/PROPAGATION | ● | ● | □ | ● | ● | □ | □ | ● | ● | ● | ● | | ● | □ | | □ |
| HURRICANE LANDFALL FORECASTS | ● | ● | | ● | ● | □ | | | | ● | ● | | ● | | | |
| POLEWARD TRANSFER OF HEAT | ● | ● | | ● | | | | | | | | □ | | | | |
| GLOBAL CLIMATOLOGY FORECASTS | ● | □ | | ● | □ | | | ● | | | | | | ● | | □ |
| LOCAL/REGIONAL WEATHER FORECASTS | ● | □ | | ● | □ | ● | | ● | ● | ● | ● | ● | ● | ● | | ● |
| COASTAL | ● | □ | □ | □ | ● | | ● | | | | | | | | | |
| WAVE PROPAGATION NEAR SHORES | | | □ | | ● | | | □ | | ● | ● | | ● | | | □ |
| TRANSPORT OF POLLUTANTS/CHEMICALS/NUTRIENTS | ● | □ | | | ● | | □ | | ● | | | | | | ● | |
| COASTAL UPWELLING | □ | | | ● | ● | | | | ● | | □ | □ | | | | |
| SHORELINE/ESTUARY CURRENT DYNAMICS | ● | | | | ● | | | □ | ● | | ● | □ | ● | | □ | □ |
| TIDAL BEHAVIORS | | | ● | | | | ● | | | | □ | | □ | | | |
| WATER PILEUP FROM STORMS | | | ● | | | | ● | | | □ | ● | | ● | | | □ |
| FRESH WATER INFLUX | ● | □ | | | ● | | | | □ | | | | | | □ | |
| SHOAL AND SHORELINE DYNAMICS | □ | | | | ● | | ● | □ | | | ● | | ● | | | |
| KELP EXTENT | | | | | ● | | | | □ | | | | □ | | | |
| ICE PROCESSES | □ | □ | □ | | ● | | □ | | | | | | | | | |
| ICE DISTRIBUTION/EXTENT/AGE | □ | ● | | | ● | | | | | | | ● | | | | □ |
| ICE FORMATION/RIDGING/BREAKUP | | | | | ● | | | | | | | ● | | | | |
| ICE LEADS LOCATION | □ | | □ | | ● | | □ | | | | | ● | | | | |
| ICE TRANSPORT | | | | | ● | | | ● | | | | ● | | | | □ |
| RESOURCE USE MANAGEMENT | □ | □ | | □ | ● | | | | | | | | | | | |
| SHIP/TANKER LOCATION | | | | | ● | | | ● | | | | | | | ● | |
| POLLUTION SPILLS MONITOR | □ | □ | | | ● | | | | | | | | | | ● | |
| FISH YIELD FORECASTS | ● | ● | | ● | | | | | ● | | | | | | | |
| FISHING BOAT LOCATION | | | | | ● | | | | ● | | | | | | | |
| FISH SCHOOL LOCATION | | | | | ● | | | | ● | | | | | | | |

Adapted from Vol. II: SEASAT Report

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although the micro processes may vary somewhat due to the different wavelengths of the energy having different transmissivities from the atmospheric column or from the ocean. The different microwave and infrared wavelengths allow the separation and quantification of the various effects using remote sensing techniques from satellite distances.

At the present, only SEASAT-A is an approved program; however, a possible program plan leading to an operational SEASAT system is presented in Figure 2.1 and consists of three distinct stages:

- Developmental SEASAT
- Interim Operational SEASAT
- Full Capability Operational SEASAT

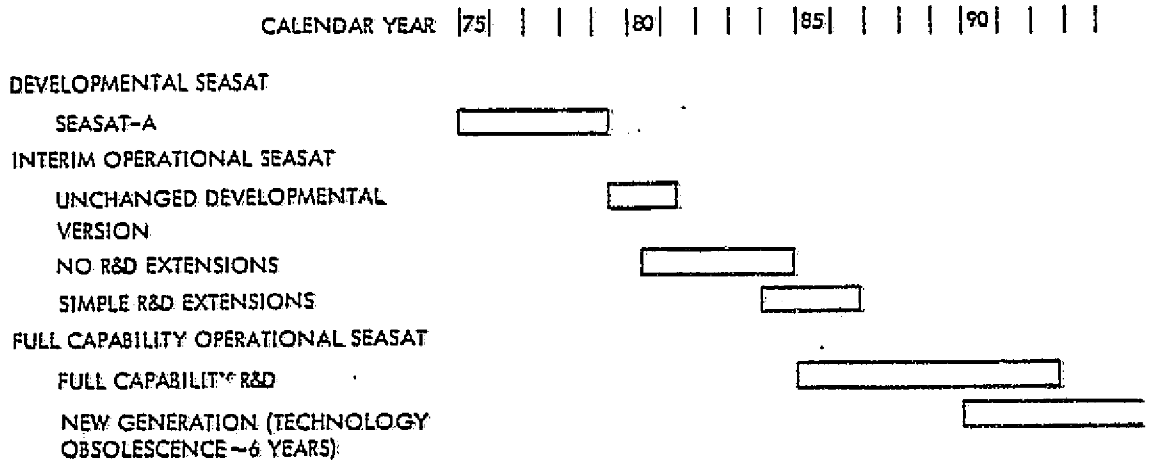


Figure 2.1 Postulated SEASAT Inflight Schedule
(Source: Vol. II SEASAT Report)

## 2.2 SEASAT-A

The first developmental satellite (SEASAT-A) is to be launched in 1978 and is a single satellite in which the sensors are designed for a nominal one-year life while the spacecraft subsystems are sized for a three-year life. In the 1980-1983 period, an interim operational SEASAT system is possible with three satellites providing twice-a-day global coverage. The full capability operational SEASAT system with six satellites could become viable in 1985 with a new SEASAT generation coming into being about every six years, representing both a reasonable life expectancy and a typical technology-obsolescence period. Only the first element of the program, SEASAT-A, will be considered in the current analysis.

SEASAT-A provides the main five-sensor complement summarized in Table 2.2: altimeter, scatterometer, scanning multifrequency microwave radiometer, visible and infrared radiometer, and synthetic aperture radar; but the accuracies and resolutions are limited to those readily obtainable, due to either the present state-of-the-art or to the ability of existing spacecraft systems to accommodate sensor support requirements. The major difference between SEASAT-A and previous earth observation satellites is the use of both active and passive microwave sensors in order to achieve an all-weather capability.

SEASAT-A, which is to have a minimum life in orbit of one year and a three-year potential, will be considered as an interim step to achieving global coverage of all oceanographical, climatic, coastal, and ice process measurements desired by the SEASAT users. The first six months of operation will be dedicated to demonstration, calibration, and

| Table 2.2 SEASAT-A Sensor Characteristics | | | | |
|---|---|---|---|---|
| Compressed Pulse Altimeter | Microwave Scatterometer | Synthetic Aperture Imaging Radar | Scanning Multi Frequency Microwave Radiometer | Visible and Infrared Radiometer |
| Global ocean topography | Global wind speed and direction | Wavelength spectra | Global all-weather temperature | Global clear-weather temperature |
| | | | Global wind amplitude | Global feature identification |
| Global wave height | | Local high resolution images | Global atmospheric path corrections | |
| 13.9 GHz | 13.9 or 14.595 GHz | 1.35 GHz | 6.6, 10.69, 18, 22.235, 37 GHz | 0.52 - 0.73 µm<br>10.5 - 12.5 µm |
| 1 m Parabola | 5-2.7 m Stick Arrays | 14 x 2 m Array | 0.8-m Offset Parabola | 12.7 cm Optics |
| 2.5 kW Peak | 125 W Peak RF | 800 W Peak | ± 20-25-deg Cross Scan | 360-deg Scan |
| 125 W Ave | 165 W Ave | 200-250 W Ave | 50 W | 10 W |
| 8 kb/s | 2 kb/s | 15-24 Mb/s | 4 kb/s | 12 kb/s |
| SKYLAB/GEOS-C | SKYLAB | APOLLO 17 | NIMBUS G | ITOS |

Source: Volume II SEASAT Report

special experiments. During the remaining time (to end of life), the system has the potential to function near operationally with a short turn-around time (less than three hours) for the availability of processed and located data. The objectives of SEASAT-A are to demonstrate a capability for measuring global ocean dynamics and physical characteristics, to provide useful data for user applications, to demonstrate key features of an operational system, and to help determine the economic and social benefits of user organization products and services.

# 3. RISKNET PROGRAM DESCRIPTION*

RISKNET is an interactive computerized project management software package capable of supplying invaluable assistance in the management and monitoring of any project. As a scheduling aid, RISKNET can be applied to diverse areas ranging from a hardware production line to research assignments in an office situation. The major purpose of RISKNET is to analyze the effects of risk on the functional operations of a particular system. Once a system (or a set of alternative systems) has been well defined, a RISKNET analysis can be run to create computer outputs which are in probabilistic terms of both the total project time and the total project cost of the system. The understanding of the ranges of time and cost allow for a more realistic view of the system from the standpoint of risk while the inclusion of both time and cost in the model allows for sensitivity analyses on the time/cost trade-offs of alternative total system configurations.

The initial step in the RISKNET process is to devise a network from the available data that coherently relates each activity and milestone to every other. The information for this network can be taken from a PERT-type production network, a set of contracts containing delivery dates, or even a simple production schedule. The precedent relationships must be established taking care to avoid any ambiguities, conflicts, or contradictions in the overall system schedule. The RISKNET

*For a more detailed explanation of RISKNET, refer to Appendix A, RISKNET User's Guide.

network alone is frequently a source of great benefits to the project manager as the network summarizes, in a visual form, the proposed schedule of activities and logical bottlenecks which can be quickly identified and corrected.

The network consists of nodes (events, milestones) connected by arcs (steps, activities). Associated with each activity there is a time distribution, a fixed cost, and a variable cost. Associated with each milestone there are a set of input activities (perhaps empty), a rule to determine when the milestone is achieved, a set of output activities (perhaps empty), and a rule to determine the output activities to be initiated once the milestone has been achieved. The relationship among activities and milestones is quite flexible in that several activities can be occurring simultaneously, some activities may never be completed once begun, or some milestones may never be achieved. It should be emphasized here that the only numerical data required once the network has been constructed is the time distribution, the fixed cost, and the variable cost as a linear function of time for every activity in the network.

Once the network is defined and the required numerical data gathered, the input data files for RISKNET must be prepared to correspond with the available information. The input structure is straightforward with the first input record giving a title to the specific network being run, the second giving the number of iterations through the network, followed by a set of records defining the activities and a set of records defining the milestone rules. Other than the title, the only record which requires thoughtful consideration is the record defining the number of iterations. In general, this number should initially be kept small (such as 50) for the debugging and exploratory simulations of the network. The general trends will be adequately displayed when this number of iterations is used. However, for production runs or runs requiring more statistical significance a larger number of iterations (such as 500) is recommended. The larger number of iterations will yield more nearly continuous probability distributions for time and cost as well as higher statistical significance for the values.

The output of RISKNET is in graphical form and consists of histograms of both the probability distribution and the cumulative distribution for the total time and cost to complete the project at each of the terminal nodes. The same histograms are repeated for the total system. In addition, the probability distributions of the project terminating at each of the possible terminal nodes are given. The output also contains the mean and variance of all of the above distributions.

The above RISKNET outputs constitute invaluable and unique information for the project manager since they yield a graphic understanding of the risks involved in the total system. The real benefit of RISKNET, however, is the ability to monitor the actual progress of a system by altering the times and costs of completed activities to their known constant values and rerunning the network. The new outputs can then be evaluated to determine the changes in the expected time and cost of the current system. As more activities are completed, the project manager is less uncertain about the completion time and cost although the initial estimates might vary from the updated estimates due to changes in the expected versus actual time and cost for a set of activities.

A further use of RISKNET is to analyze the quantitative effects of alternative system schedules. One frequently used alternative plan is that of a "crash" program, that is, a high risk, short duration project versus a "normal" program which has lower risk but a longer duration. Often, the completion time for the high risk alternative does not deviate statistically from the crash program. Another alternative which is frequently used is the addition of feasibility studies or additional test phases to lower the risk of total program failure at some additional cost. The quantitative effect of these studies or tests on the total system can be directly calculated using RISKNET. Further alternative RISKNET structures can be constructed to adapt to the specifications of virtually any system.

# 4. APPLICATION OF RISKNET TO SEASAT-A

## 4.1 Overview of the Process

The development of the five sensors for SEASAT-A is being accomplished, insofar as it is possible, in an independent manner with a separate organization bearing the major responsibility for each sensor. Furthermore, the bus and the sensor module, which must interface with the launch vehicle, are being developed by still another organization. Once each of the sensors has been built or acquired, it must be integrated and tested as part of a coherent total satellite.

As in any such program, well-defined objectives in terms of times and costs are established which are dependent upon the timely and accurate completion of each one of the interrelated tasks. Necessary items for the successful completion of a program include:

- Set of well-defined interfaces among the contractors,
- An integrated schedule that affords sufficient time to resolve possible development problems,
- A sound systems engineering approach which emphasizes both technical and schedule integration and interface control.

Without a firm understanding of the above items, successful project management is difficult, if not impossible, to achieve.

As the SEASAT-A program is quite diversified in terms of the number of contractors assigned to specific tasks, a detailed overview of the entire development plan is very complex because one would have to monitor in depth the activities of each separate group and the impact of respective schedule changes. A sensitivity analysis of such minor schedule changes on the total schedule would be quite tedious when the number and type of such minor changes are considered. The approach of the present analysis is to monitor only the major milestones of the project in the total system network and to model the details of each sensor separately. In this manner, the sensitivities of the models to schedule changes within each sensor can be monitored. Once suitable sensor models are developed and tested, then the major interfaces will be combined into a simplified overview model of the entire SEASAT-A program.

### 4.2 Process Implementation for SEASAT-A

The analysis of the SEASAT-A program will be accomplished in a modular form with an independent RISKNET analysis being done on the five major sensors: scatterometer, altimeter, scanning multifrequency microwave radiometer, synthetic aperture radar, and visible and infrared radiometer. Detailed sensitivity analyses will be run on each of the five sensor models until a suitable macro model of the sensor can be developed. The five sensor macro models will then be integrated into the total system network which will include the sensor module and bus development plans. The total network will then be analyzed and used in a continual interactive monitoring mode as the specific milestones are reached or violated.

The process of designing a RISKNET analysis for any general program is fully described in Appendix A; however, the specific implementation of the process for SEASAT-A is as follows:

1. Acquire detailed project milestone data contracts, PERT networks, etc., including the strict definition of interfaces of the various work tasks.
2. Use the milestone data to create an initial network of approximately 50 activities.

3. Present the initial network to the project manager to ascertain the validity of the selected activities and the precedent relationships.

4. Redesign the network to correspond to alterations suggested by the project manager.

5. Run the cases of the network to yield the output histograms of cost and time.

6. Present the results to the project manager and go to (4) if necessary.

Two examples of the initial phase networks are presented in Sections 4.3 and 4.4 for the scatterometer and altimeter, respectively. These examples show two different approaches for creating the initial network based on data availability. The times and costs for the activities have not been exhaustively included as suitable estimates could not be derived from the available data for each activity. Gross estimates could be made on the times and costs; however, it was felt that the project manager would be the most capable person to assign the respective time distributions and costs for the activities.

Further steps in the analysis will be to create similar networks for the other sensors and to spend time with each project manager to revise and improve upon the current networks. Once the sensor models have been thoroughly tested, then the overall SEASAT-A program will be analyzed using an overview network consisting of only major program interfaces.

### 4.3 Example I: Scatterometer Network

The microwave scatterometer has been selected as the remote sensor on SEASAT-A for measuring the direction and magnitudes and ocean and surface winds. The SEASAT-A User Panel has established this objective as one of the requirements of the SEASAT-A mission because surface wind data are necessary for monitoring and predicting ocean phenomena (e.g., hazardous sea conditions) and for general weather forecasting. Lack of this data has precluded improved long-range weather forecasting for both oceans and continental areas.

Microwave scatterometers have previously been flown in aircraft such as NASA-LRC's AAFE Radscat, NASA JSC's 13.3 GHz Scatterometer, and NRL's Sea Clutter study as well as on the S-193 Skylab Spacecraft. These scatterometers have undergone considerable test and development; therefore, both the electronic systems and the scientific principles are no longer in the research stage but have been proven for the SEASAT-A application.

A two-phase contractual effort is being conducted to accomplish the design and manufacture of the SEASAT-A Satellite Scatterometer (SASS). Phase I will provide the necessary designs, drawings, and documentation for use in the fabrication of flight hardware for the SASS experiment, generate procurement specifications with early emphasis on long lead-time hardware items, and present the preliminary and critical design reviews. In Phase II, the fabrication and development of the SASS will be completed in accordance with the Phase I specifications, designs, and plans.

The necessary contracts have been let by NASA Langley Research Center to affect the completion of the SASS. The major contract is with General Electric Company of Philadelphia, Pennsylvania to design, develop, fabricate, and provide launch support for the SASS. The GE contract, which is a cost plus performance award fee contract, is divided into Phase I and Phase II as above. GE will serve as the prime contractor having the overall responsibility for the project.

A second two-phase contract, of the type cost plus fixed fee, was awarded to Aerojet-General Corporation of Azusa, California to design and develop the SASS Antenna. The deliveries of Aerojet hardware items will affect the timing of the GE contract.

The third contract, fixed price, was awarded to Hughes Aircraft Company of Torrance, California to design, fabricate, test, and deliver the traveling wave tubes for the SASS.

The available data at the time of this first cut RISKNET analysis were the contracts of GE, Aerojet, and Hughes, which specify the delivery dates of specified items. As no overview network of the project plan was available, a network representing the interfaces of delivery dates of the three contractors was constructed. The delivery dates specified in the contracts are summarized in Tables 4.1 to 4.5.

Table 4.1 Schedule GE to NASA

| Event | Quantity | Months After Date of Contract |
|---|---|---|
| Preliminary Design Review | | 4 |
| Critical Design Review | | 8 |
| EQBM Subsystem Test | | 14 |
| Delivery of EQBM | 1 | 20 |
| Ground Support Equipment | 1 Lot | 20 |
| Delivery of FM | 1 | 24 |
| Spare Parts | 1 Lot | 24 |
| Documentation | 1 Lot | As specified in Exhibit 2 of Statement of Work |

Adapted from GE Contract

Table 4.2 Schedule NASA to GE

| Event | Quantity | Months After Date of Contract |
|---|---|---|
| S-193 EMI Test Set Including Field Support Waveguide Kits | 1 each | 2 |
| Residual S-193 Electrical Test Set (NAS9-11195) | 1 Lot | 7 |
| Hughes 100-W TWT (EM) | 1 each | 12 |
| Hughes 100-W TWT (QM) | 1 each | 16 |
| Brassboard Antenna | 1 each | 16 |
| Hughes 100-W TWT (FM) | 1 each | 20 |
| Fan Beam Antennas | 5 each | 21 |

Adapted from GE contract

Table 4.3 Schedule Aerojet to NASA

| Event | Quantity | Months After Date of Contract |
|---|---|---|
| Phase I | | 4 |
| Brassboard Model | 1 each | 8 |
| Mechanical Interface Mass Model (4 Antennas) | 1 each | 9 |
| EQBM | 1 each | 15½ |
| Flight Models | 4 each | 20 |
| Ground Support Equipment | As specified | 20 |
| Documentation | | As specified in Exhibit 2 of Statement of Work |

Adapted from Aerojet contract

| Table 4.4 Schedule Hughes to NASA | | |
|---|---|---|
| Event | Quantity | Months After Date of Contract |
| 100-W TWT (EM) | 1 | 11 |
| 100-W TWT (QM) | 1 | 15 |
| 100-W TWT (FM) | 1 | 18 |
| Documentation | As specified in Exhibit 6 of Statement of Work | As specified in Exhibit 6 of Statement of Work |

| Table 4.5 Schedule NASA to Hughes | | |
|---|---|---|
| Event | Quantity | Months After Date of Contract |
| Isolators | 2 sets | 6 |

Given the above schedules of deliveries, a network was constructed to represent the interfaces among the contractors. The network is presented in Figure 4.1, and the description of each arc is given in Table 4.6.

## 4.4 Example II: Altimeter Network

The radar altimeter, one of five major sensors in the SEASAT-A satellite, began with the inception of preliminary design reviews in August of 1975 and is scheduled for completion in approximately November of 1977. The altimeter is being included on board SEASAT-A due to its capabilities of precision in measuring surface topography of ocean wave heights, currents, tides, and coastal water swellings. The particular altimeter under construction has experienced two evolutionary phases of modifications and improvements. The altimeter's current design has evolved from the altimeter used on GEOS-C, which had been previously developed for the SKYLAB. Several parts of the SKYLAB altimeter have been carried through unchanged to SEASAT-A.

The radar altimeter's design structure is composed of several components which are being constructed simultaneously. At various project milestones, these small parts are scheduled to be tested and integrated into the three major operational sections of the altimeter. Table 4.7 lists the three major sections and their components.

A production network was devised by the Applied Physics Laboratory (APL) of Johns Hopkins University, incorporating all phases of production for the radar altimeter. Since APL is building the major portion of the altimeter, it requires such a system schedule. The network establishes a system flow whereby the precedent relationships

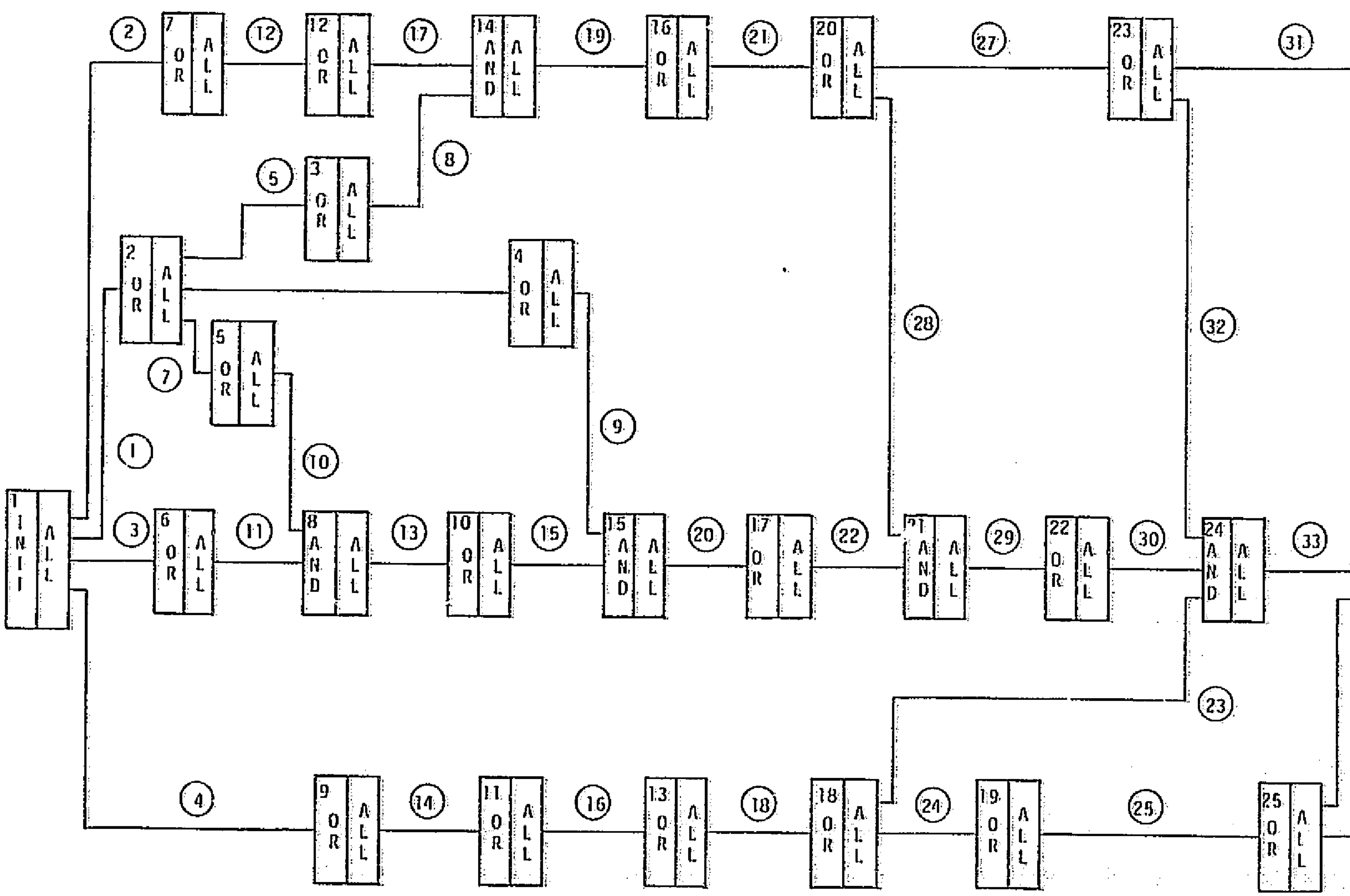


Figure 4.1 SEASAT-A Scatterometer RISKNET Network

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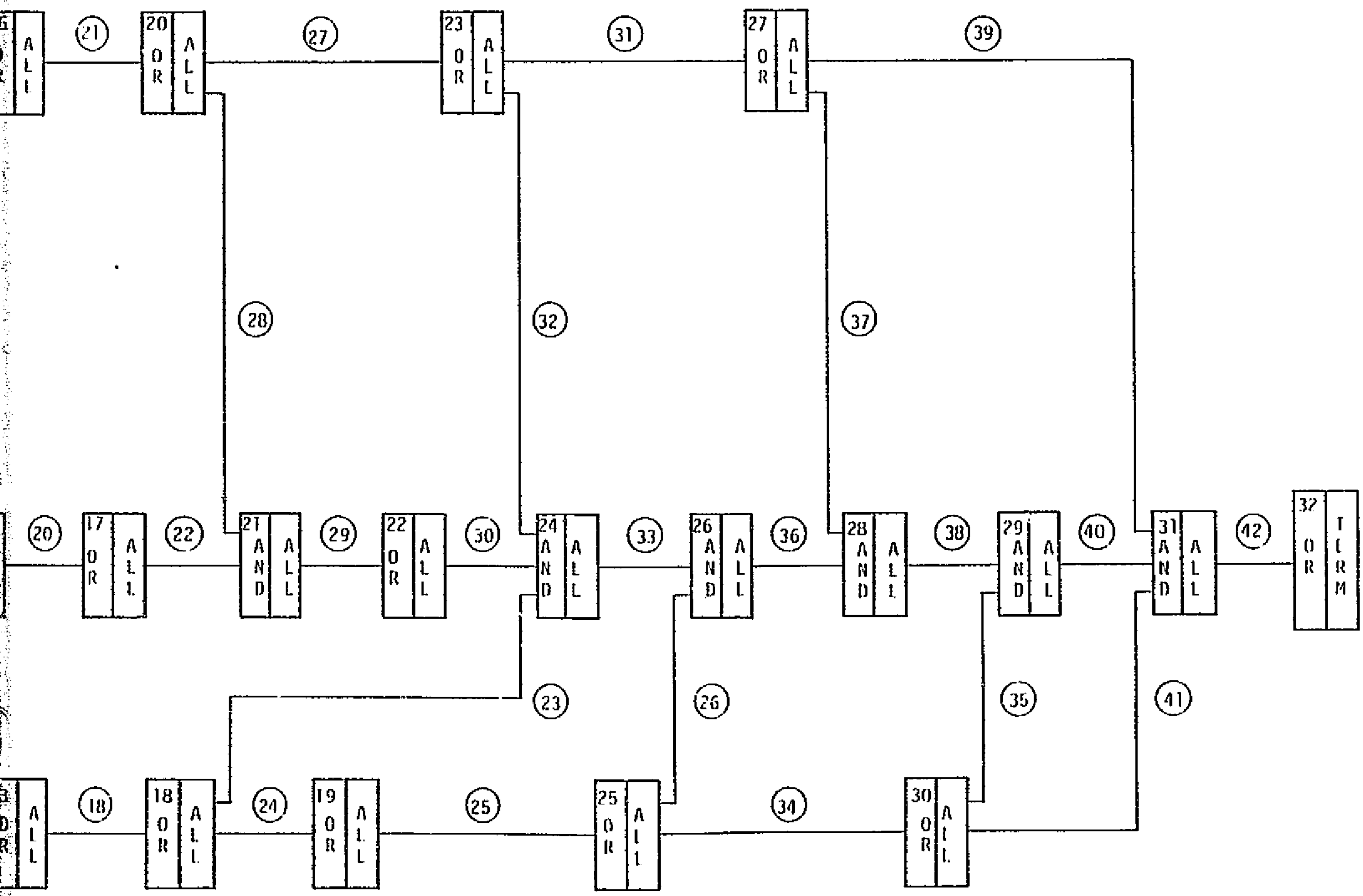



Figure 4.1 SEASAT-A Scatterometer RISKNET Network

FOLDOUT FRAME

Table 4.6 RISKNET Arc Description Sheet
SEASAT-A Scatterometer (Version I)

| Arc | From | To | Time | Cost | Description |
|---|---|---|---|---|---|
| 1 | 1 | 2 | | | NASA procurement startup |
| 2 | 1 | 7 | | | Hughes startup |
| 3 | 1 | 6 | | | GE startup |
| 4 | 1 | 9 | | | Aerojet startup |
| 5 | 2 | 3 | | | NASA procurement: isolators |
| 6 | 2 | 4 | | | NASA procurement: Residual S-193 |
| 7 | 2 | 5 | | | NASA procurement: S-193 EMI Test |
| 8 | 3 | 14 | | | NASA delivery: Isolators to Hughes |
| 9 | 4 | 15 | | | NASA delivery: Residual S-193 to GE |
| 10 | 5 | 8 | | | NASA delivery: S-193 EMI Test to GE |
| 11 | 6 | 8 | | | GE preliminary review |
| 12 | 7 | 12 | | | Hughes preliminary review |
| 13 | 8 | 10 | | | GE preliminary review |
| 14 | 9 | 11 | | | Aerojet preliminary review |
| 15 | 10 | 15 | | | GE critical review |
| 16 | 11 | 13 | | | Aerojet critical review |
| 17 | 12 | 14 | | | Hughes critical review |
| 18 | 13 | 18 | | | Brassboard Model completion Aerojet |
| 19 | 14 | 16 | | | Hughes Phase II startup |
| 20 | 15 | 17 | | | GE Phase II startup |
| 21 | 16 | 20 | | | Hughes EM completion TWT |
| 22 | 17 | 21 | | | GE expected delivery: Hughes EM TWT |

Table 4.6 RISKNET Arc Description Sheet
SEASAT-A Scatterometer (Version I)

(continued)

| Arc | From | To | Time | Cost | Description |
|---|---|---|---|---|---|
| 23 | 18 | 24 | | | Aerojet delivery: brassboard to GE antenna |
| 24 | 18 | 19 | | | Aerojet mechanical interface completion |
| 25 | 19 | 25 | | | Aerojet EQBM completion |
| 26 | 25 | 26 | | | Aerojet delivery: EQBM to GE |
| 27 | 20 | 23 | | | Hughes QM completion TWT |
| 28 | 20 | 21 | | | Hughes delivery: EM to GE TWT |
| 29 | 21 | 22 | | | GE EQBM subsystem test |
| 30 | 22 | 24 | | | GE delivery EQBM |
| 31 | 23 | 27 | | | Hughes FM completion |
| 32 | 23 | 24 | | | Hughes delivery: QM to GE |
| 33 | 24 | 26 | | | GE expected delivery: EQBM Aerojet |
| 34 | 30 | 29 | | | Aerojet delivery: FM to GE |
| 35 | 25 | 30 | | | Aerojet FM completion |
| 36 | 26 | 28 | | | GE Expected delivery: Hughes FM |
| 37 | 27 | 28 | | | Hughes delivery: FM to GE |
| 38 | 28 | 29 | | | GE expected delivery: Aerojet FM |
| 39 | 27 | 31 | | | Hughes delivery: documentation |
| 40 | 29 | 31 | | | GE delivery: FM and final report |
| 41 | 30 | 31 | | | Aerojet delivery: Documentation and Support |
| 42 | 31 | 32 | | | GE Sensor Integration Validation |

Table 4.7 Major Sections and Components of the SEASAT-A Altimeter

A. Radiofrequency (RF) Section

1. Antenna
2. Travelling Wave Tube Amplifier (TWTA)
3. Dispersive Delay Line (DDL) including the Dispersive Delay Line Filter
4. Up-Converter/Frequency Multiplier (UCFM)
5. Receiver
6. Microwave Transmission (MT)

B. Signal Processor Section

1. High Speed Waveform Sampler
2. Digital Filter Bank
3. Adaptive Tracker
4. Synchronizer/Acquisition/Calibrate Unit
5. Interface and Control

C. Low Voltage Power Suoply

1. Powerflow

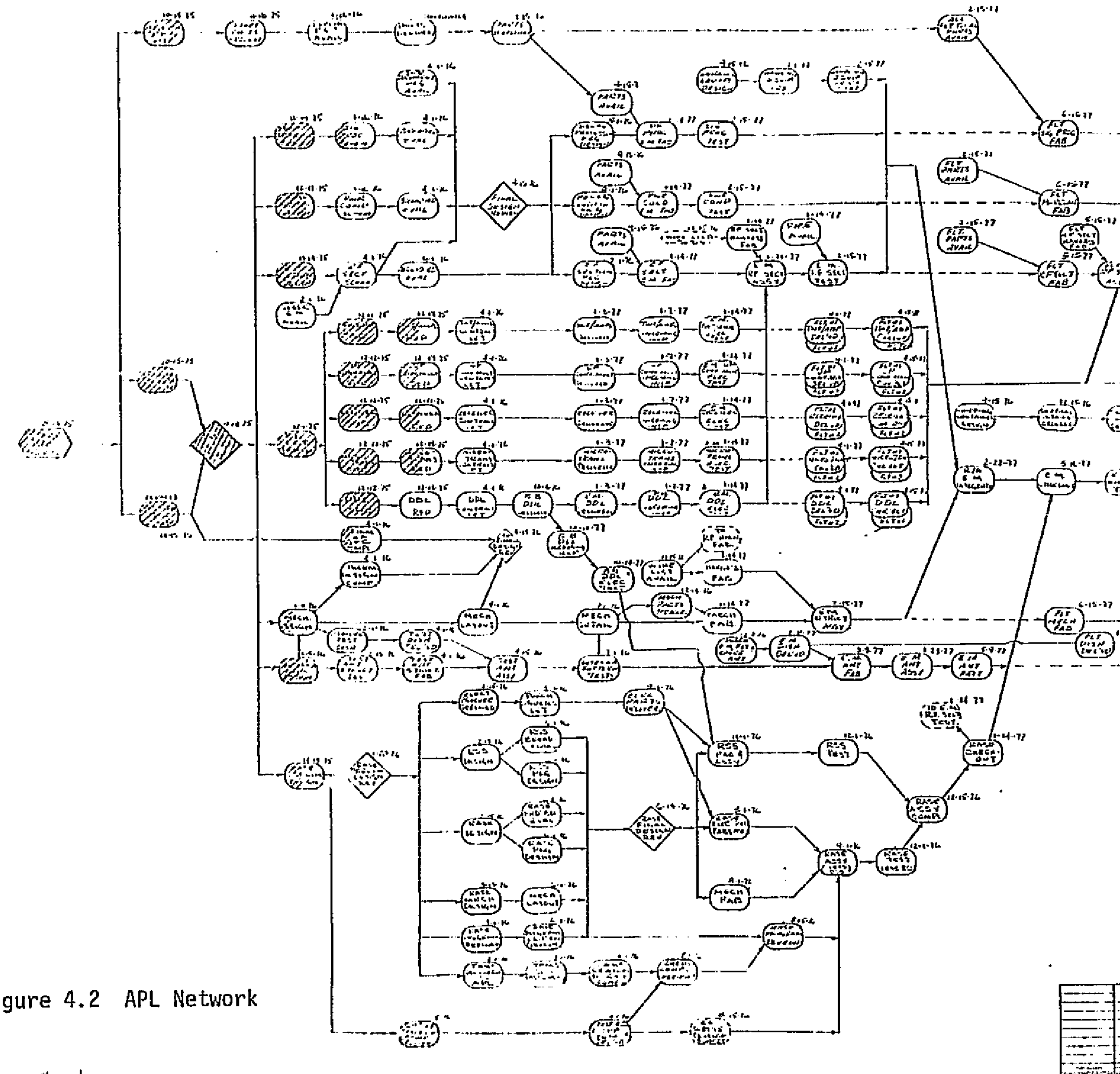
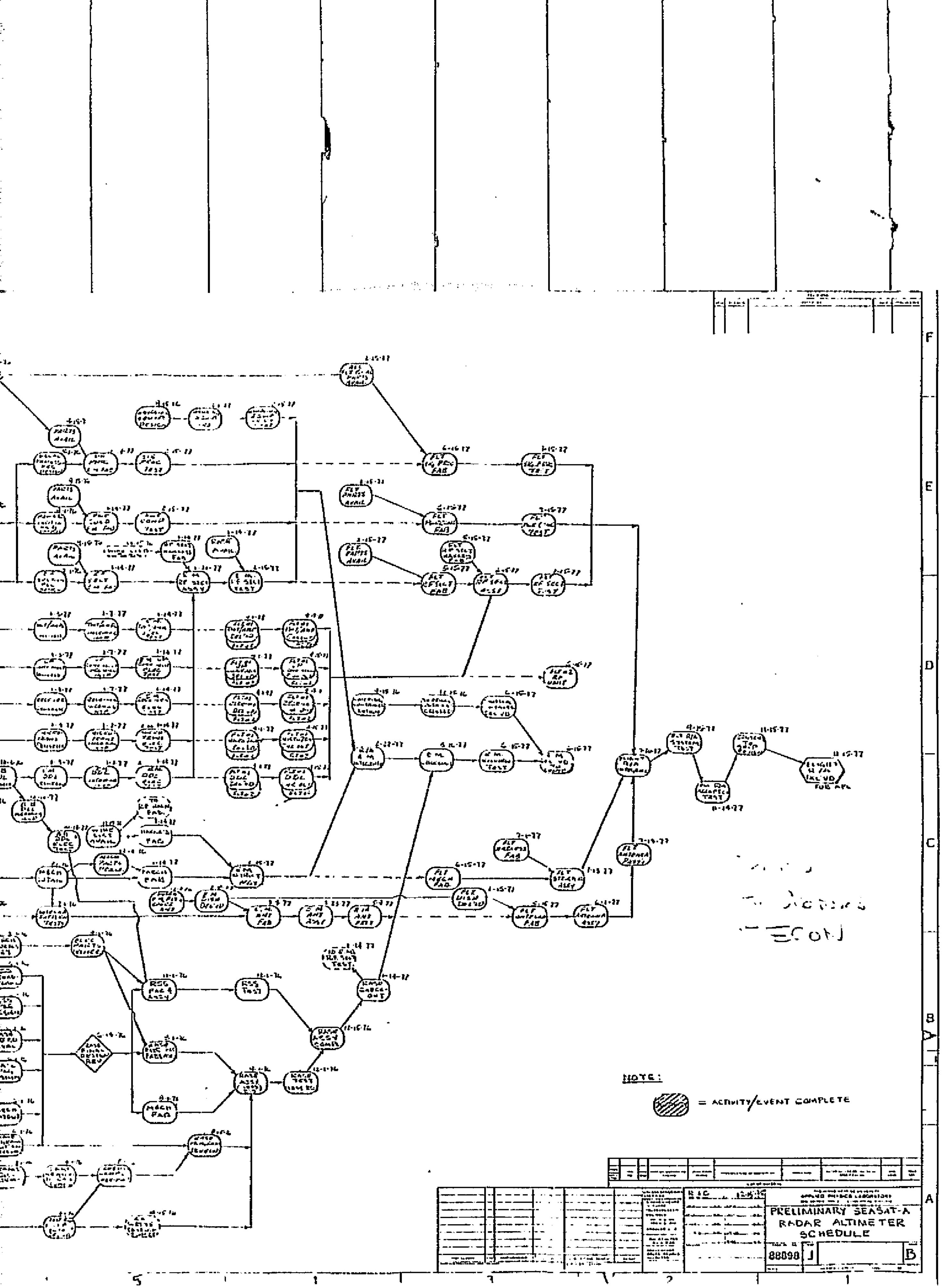


Figure 4.2 APL Network

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must be satisfied at various milestones before further production activities are initiated. The following three companies have been awarded contracts by APL to build the associated parts:

1. Hughes Aircraft Company (Selection Dynamic Division) - Traveling Wave Tube Amplifier (TWTA) (engineering model and flight model).

2. Andersen Laboratories, Inc. - Dispersive Delay Line Filter (engineering model and flight model) and DDL Brassboard.

3. Zeta Laboratories, Inc. - Up-converter/Frequency Multiplier (engineering model and flight model).

4. APL - remaining parts of the altimeter.

The APL network is constructed in detail so as to benefit the production management officials. For the purpose of a RISKNET analysis, a more generalized network is preferable. APL's network has been condensed to include the initial and completion steps involved in each part of the altimeter. Care has been taken not to alter any production precedences; however, this network is intended as a first cut and is subject to further revisions. Most of the production steps are terminated with a performance test. The time in months, for each step, was adapted from APL's chart. Figure 4.2 shows APL's network, and Figure 4.3 shows the condensed RISKNET version. The two diagrams differ in their form. APL's network is essentially one of management tools used to follow production progress. Each activity is represented by a block. When that activity is finished, an arrow sends it to the next step. When conducting a RISKNET analysis, the lines (or arcs) are the activities (refer to RISKNET User's Guide). Table 4.8 is an arc description sheet including the arc number, its destination from node to node, time in

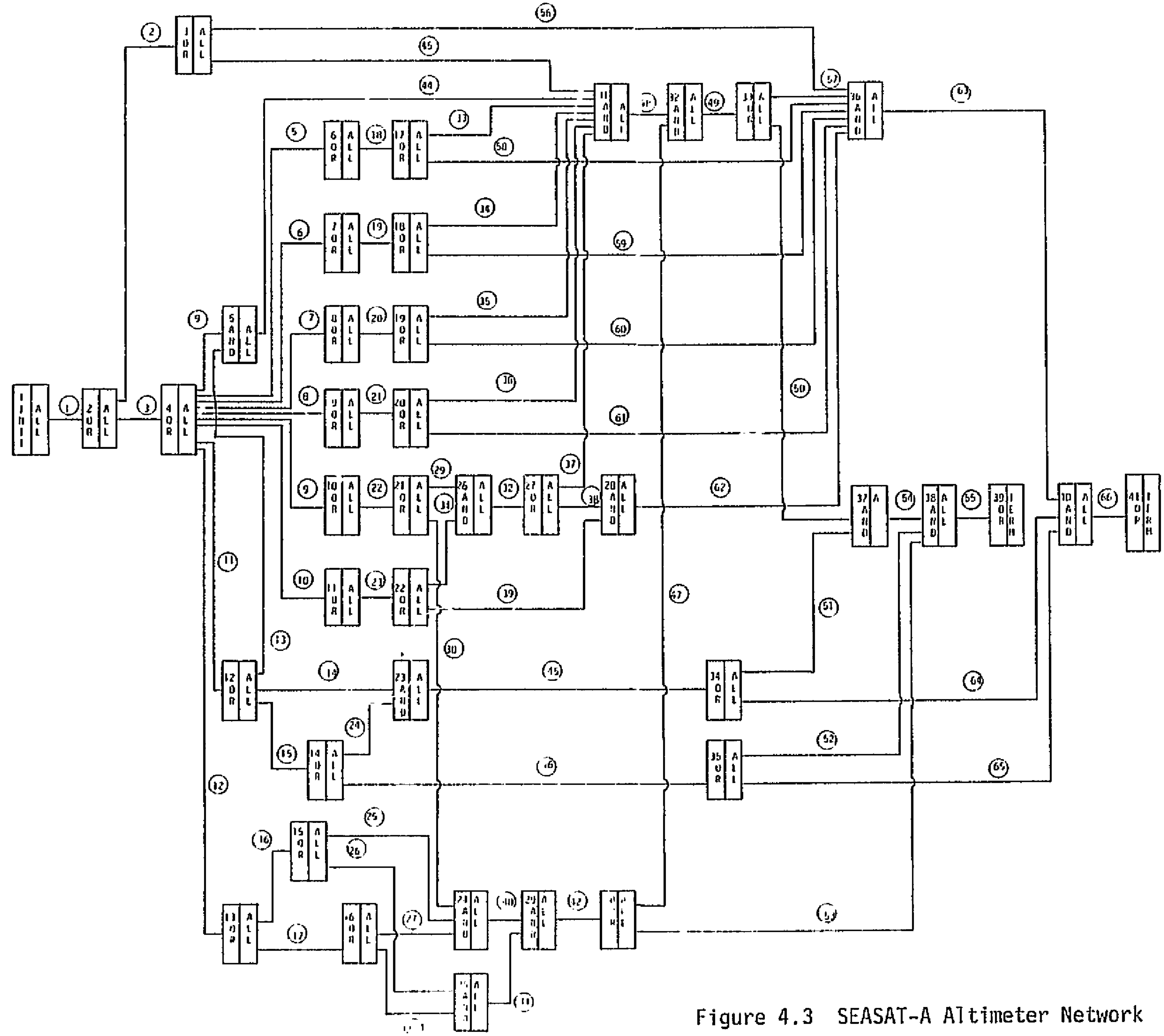


Figure 4.3 SEASAT-A Altimeter Network

Table 4.8 RISKNET Arc Description Sheet--SEASAT-A Altimeter (Version I)

| Arc | From | To | Time (months) | Description |
|---|---|---|---|---|
| 1 | 1 | 2 | 0 | Start altimeter program |
| 2 | 2 | 3 | 2.0 | APL start precursor parts procure |
| 3 | 2 | 4 | 3.0 | APL preliminary design review (PDR) |
| 4 | 4 | 5 | 0 | Delay time between PDR and final design review (FDR) |
| 5 | 4 | 6 | 4.5 | Hughes TWT/AMPL contract begins |
| 6 | 4 | 7 | 4.5 | Zeta UCFM contract begins |
| 7 | 4 | 8 | 4.5 | APL receiver work begins |
| 8 | 4 | 9 | 4.5 | APL MT work begins |
| 9 | 4 | 10 | 4.5 | Andersen DDL contract begins |
| 10 | 4 | 11 | 4.5 | Andersen DDL filter contract begins |
| 11 | 4 | 12 | 2.0 | APL mechanical design and antenna work begin |
| 12 | 4 | 13 | 2.0 | APL RASE PDR |
| 13 | 12 | 5 | 3.0 | Mechanical design shipped to APL FDR |
| 14 | 12 | 23 | 0 | Mechanical design shipped to APL EM structure assembly |
| 15 | 12 | 14 | 3.0 | APL test antenna assembly |
| 16 | 13 | 15 | 1.3 | APL purchase orders begin |
| 17 | 13 | 16 | 4.8 | APL RASE FDR |
| 18 | 6 | 17 | 9.5 | Hughes EM TWT/AMPL build and checkout |
| 19 | 7 | 18 | 9.5 | Zeta EM UCFM build and checkout |
| 20 | 8 | 19 | 9.5 | APL EM receiver build and checkout |
| 21 | 9 | 20 | 9.5 | APL EM MT build and checkout |

Table 4.8 RISKNET Arc Description Sheet--SEASAT-A Altimeter (Version I) (continued)

| Arc | From | To | Time (months) | Description |
|---|---|---|---|---|
| 43 | 3 | 31 | 8.0 | APL parts delivery and test |
| 44 | 5 | 31 | 5.0 | APL final design review |
| 45 | 23 | 34 | 8.5 | APL EM structure assembly |
| 46 | 14 | 35 | 9.7 | APL EM antenna assembly |
| 47 | 30 | 32 | 0 | Delay time |
| 48 | 31 | 32 | .25 | APL EM RF section assembly |
| 49 | 32 | 33 | 1.0 | APL sig. proc., pwr. cond., EM RF section checkout |
| 50 | 33 | 37 | 0 | APL sig. proc., pwr. cond., EM RF section delivery |
| 51 | 34 | 37 | 0 | EM structure assembly delivery |
| 52 | 35 | 38 | 0 | EM antenna delivery to APL EM checkout and delivery |
| 53 | 30 | 38 | 0 | RASE delivery to APL EM checkout and delivery |
| 54 | 37 | 38 | .25 | EM R/A Integrate |
| 55 | 38 | 39 | 3.8 | APL EM checkout and delivery |
| 56 | 3 | 36 | 8.0 | APL parts delivery and test |
| 57 | 33 | 36 | 0 | Delay time |
| 58 | 17 | 36 | 3.0 | Hughes FM TWT/AMPL build and checkout |
| 59 | 18 | 36 | 3.0 | Zeta FM UCFM build and checkout |
| 60 | 19 | 36 | 3.0 | APL FM receiver build and checkout |
| 61 | 20 | 36 | 3.0 | APL FM MT build and checkout |
| 62 | 28 | 36 | 3.0 | APL FM DDL build and checkout |

Table 4.8 RISKNET Arc Description Sheet--SEASAT-A Altimeter (Version I) (continued)

| Arc | From | To | Time (months) | Description |
|---|---|---|---|---|
| 22 | 10 | 21 | 6 | Andersen BB DDL delivery to APL |
| 23 | 11 | 22 | 1.5 | Andersen EM DDL filter build and checkout |
| 24 | 14 | 23 | 2.5 | Antenna shipped to APL EM assembly |
| 25 | 15 | 24 | 6.0 | Purchase orders delivery to APL RSS |
| 26 | 15 | 25 | 6.0 | Purchase orders delivery to APL RASE |
| 27 | 16 | 24 | 0 | RASE FDR delivery to RSS assembly |
| 28 | 16 | 25 | 0 | RASE FDR delivery to RASE assembly |
| 29 | 21 | 26 | 0 | Delay time |
| 30 | 21 | 24 | 12.3 | BB DDL shipped to RSS assembly |
| 31 | 22 | 26 | 0 | Andersen EM DDL filter shipped to APL |
| 32 | 26 | 27 | 3.5 | APL EM DDL build and checkout |
| 33 | 17 | 31 | 0 | Hughes EM TWT/AMPL delivery to APL |
| 34 | 18 | 31 | 0 | Zeta EM UCFM delivery to APL |
| 35 | 19 | 31 | 0 | EM Receiver delivery to RF section assembly |
| 36 | 20 | 31 | 0 | EM MT delivery to RF section assembly |
| 37 | 27 | 31 | 0 | EM DDL delivery to RF section assembly |
| 38 | 27 | 28 | 0 | Delay time |
| 39 | 22 | 28 | .5 | Andersen FM DDL filter build and checkout |
| 40 | 24 | 29 | 3.0 | APL RSS assembly and checkout |
| 41 | 25 | 29 | 3.0 | APL RASE (less RSS) assembly and checkout |
| 42 | 29 | 30 | 1.5 | APL RASE completion and checkout |

Table 4.8 RISKNET Arc Description Sheet--SEASAT-A Altimeter (Version I) (continued)

| Arc | From | To | Time (months) | Description |
|---|---|---|---|---|
| 63 | 36 | 40 | 3.0 | APL sig. proc., pwr. cond., and FM RF assembly and checkout |
| 64 | 34 | 40 | 5.0 | APL FM structure assembly and and delivery |
| 65 | 35 | 40 | 3.5 | APL FM antenna assembly, test and delivery |
| 66 | 40 | 41 | 4.0 | APL FM altimeter integrate, checkout and delivery |

months, and the activity's description. Table 4.9 includes a list of all the abbreviations used in the RISKNET description sheet and their meanings.

To complete the RISKNET cost analysis, conferences will be held with the project manager to determine the workability of the condensed network and to specify the time ranges and the fixed and variable costs applicable to each activity. Presently, the time for each activity is entered as a constant. The constant figures (found on the arc description sheet) are preliminary figures only. Dicussions will be held on the completion times for each activity, and a range will be set from the shortest possible production period to the longest. Depending upon the variability of the range, a normal, triangular, or uniform distribution will be selected. It is possible that the times for some of the activities will remain constant.

After all of the necessary network revisions have been made and time distributions and costs are applied to each activity, the network will be analyzed on a time sharing system. Sensitivity analyses will be carried out to determine the effect of delays upon subsequent scheduling and total project competition and cost. A more specific approach to the sensitivity analyses will be outlined at a later date when the type of information which will be most useful in the management of the altimeter is apparent.

Table 4.9 Abbreviations and Meanings for Arc Descriptions for Altimeter

| | |
|---|---|
| APL | - Applied Physics Laboratory |
| TWT/AMPL | - Travelling Wave Tube Amplifier |
| MT | - Microwave Transmission |
| DDL | - Dispersive Delay Line |
| RASE | - Interfacing, Altimeter Control and Data Collection Recording and Analysis Equipment |
| EM | - Engineering Model |
| UCFM | - Up-Converter/Frequency Multiplier |
| BB | - Brassboard |
| RSS | - Return Signal Simulator |
| RF | - Radio Frequency |
| SIG.PROC. | - Signal Processor |
| PWR.COND. | - Power Conditioner |

# APPENDIX A: RISKNET USER'S MANUAL

## A.1 Introduction

RISKNET is a project management review technique that graphically depicts and analyzes a project as a schedule network of distinct tasks. The network consists of: 1) nodes (also called events or milestones) that function as logical or probabilistic gates and 2) arcs (or activities) that connect those gates and represent probabilistic times and costs for activity completion. For each node, there are both entering and exiting arcs, illustrative of a sequential process. The arcs are activities, and the gates symbolize successful completion of the incoming activities and initiation of the outgoing activities.

An unqualified amount of uncertainty exists as to when the events will occur. For this reason, an absolute time often cannot be suitably applied to an activity. A range of times is the most accurate estimation of the activity's completion time. The preferred usage of a probability distribution over a constant time is more reasonable, logically speaking, since a production schedule often encounters numerous unscheduled delays that can significantly retard progress. RISKNET provides the program manager with a monitoring device which enables him to follow the program's progress with a much greater realism than previously possible. Any delays in activity completion can be analyzed to determine the detrimental effect imposed on the completion of each succeeding activity as well as on the total project completion. The arcs are assigned both fixed and variable costs as well as a time distribution. RISKNET's ability to incorporate cost elements is extremely important because both time and cost are of great concern in management's decision processes.

RISKNET is a set of FORTRAN programs that can be run either in batch mode or from a time sharing terminal. The required input is definition of the parameters of the activities (i.e., times and costs) and decision points (i.e., input and output rules). The number of desired iterations is specified in the input data. For each iteration, the computer generates a set of random numbers selected from the range of the time distribution of each activity, which are dependent upon the specific parameters. Each set of numbers and the results generated by them constitute one iteration through the project network; therefore, the number of iterations equals the number of times through the network. After all iterations are completed, the program simulation produces the output shown in Table A.1. If there is only one terminal node, then the fourth and fifth outputs are identical to the second and third and are omitted.

A list of the steps that should be followed in performing a cost and schedule risk analysis with RISKNET is shown in Table A.2.

## A.2 RISKNET Data Description and Format

The data input procedure in a RISKNET analysis is straightforward and consists of the following steps. First, a network is constructed representing the project plan. Each arc, representing an activity, is labeled with time distributions and fixed and variable costs. The probability distribution of the activity time can be normal, uniform, triangular or constant; and the variable cost is defined as a linear function of the activity time.

| Table A.1 RISKNET Simulation Outputs |
| --- |
| • Summary of input (arc and node specifications). |
| • A probability distribution and a cumulative probability distribution of completion times for each terminal node. |
| • A probability distribution and a cumulative probability distribution of completion costs for each terminal node. |
| • A probability distribution and a cumulative probability distribution of completion times for all terminal nodes. |
| • A probability distribution and a cumulative probability distribution of completion costs for all terminal nodes. |
| • The probability that the project will reach termination at each terminal node. |

Table A.2 The RISKNET Process

- Identify all activities and decision points that might occur during the development and implementation plan.
- Ascertain the precedent relationships that exist between sets of activities.
- Determine the parameters for the time distributions for each activity.
- Determine variable and fixed costs for each activity variable. Cost is a linear function of the time distribution.
- Estimate the probability of successfully completing each activity.
- Construct the alternative project plans that may be utilized without violating the constraining precedent relationship.
- Run RISKNET for each alternative project plan and analyze the output. If from this analysis it is possible to reconfigure the networks and improve the time and cost characteristics, then do so and rerun RISKNET.
- Perform sensitivity analyses on the inputs and network structure. These analyses involve testing the effect on project termination imposed by production delays at various arcs.

The equation can be written as follows:

$$C_i = V_i t_i + F_i$$

where

$C_i$ = Total cost of activity i,

$t_i$ = Completion time for activity i,

$V_i$ = Variable cost of activity i,

$F_i$ = Fixed cost of activity i.

Table A.3 categorizes the parameters, equations, program variable, and shape of each time distribution.

Each node is assigned both an input and an output rule according to numbered conventions. The input rule establishes the conditions to be met in order to achieve the milestone, and the output rule defines in what order or under what circumstances the succeeding activities are to be initiated. The input/output rules are diagrammed and described in Table A.4, and the code number plus the associated input or output rule are summarized in Table A.5.

The first two records of the data file identify the title of the program and the desired number of iterations. All eighty columns of the first record can be used for any alphanumeric title given to the simulation while the second record is a five column, right justified integer defining the number of iterations. The remaining data records are divided into two major sections: the first identifies the arcs, and the second identifies the nodes. The user must provide the information listed in Table A.6 for each arc, and Table A.7 gives the specific FORTRAN format for these arc records.

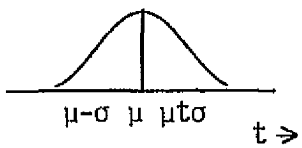
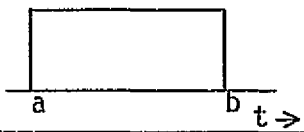
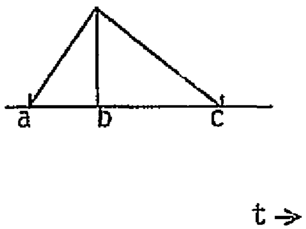
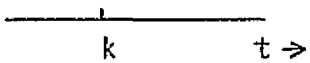
| Table A.3 RISKNET Time Distributions | | | | | |
|---|---|---|---|---|---|
| Name | Identifier | Shape | Parameter | Equation | Description |
| Normal | 1 |   | $\mu$, $\sigma$ | $f(t) = \frac{1}{\sigma\sqrt{2\pi}} \ell^{-\frac{1}{2}\left(\frac{t-\mu}{\sigma}\right)^2}$ <br> $-\infty < t < \infty$ | $\mu$ = mean <br> $\sigma$ = variance |
| Uniform | 3 |   | a, b | $f(t) = \frac{1}{b-a} \quad a \leq t \leq b$ | a = minimum time <br> b = maximum time |
| Triangular | 2 |   | a, b, c | $0 \quad t \leq a$ <br> $\frac{2}{(b-a)(c-a)} (t-a) \quad a \leq t \leq c$ <br> $\frac{2}{(b-a)(b-c)} (t-b) \quad c \leq t \leq b$ <br> $0 \quad t \geq b$ | a = optimistic time <br> b = most likely time <br> c = pessimistic time |
| Constant | 4 |   | k | $f(t) = k$ <br> $-\infty < t < \infty$ | k = constant time |

Table A.4 RISKNET Node Input/Output Rules

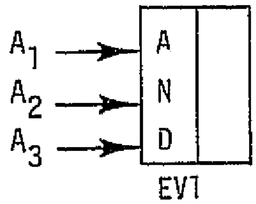
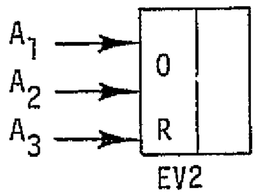
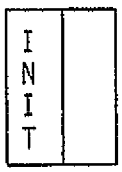
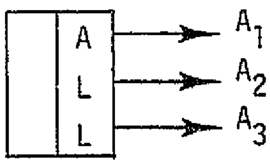
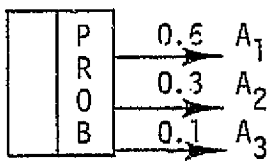
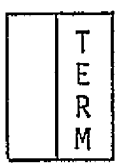
| Rule | Graphical Representation | Description |
|---|---|---|
| INPUT: | | |
| AND |  | The project event is achieved only when all of the input activities are successfully computed. In this case, all three activities must be computed before EV1 is achieved. |
| OR |  | The project event is achieved with the completion of any one of the input activities. As soon as either $A_1$, $A_2$ or $A_3$ is completed, EV2 is achieved. |
| INIT |  | This project event occurs immediately at the beginning of a simulation network. |
| OUTPUT: | | |
| ALL |  | Once the event is achieved, all of the output activities are initiated simultaneously. |
| PROB |  | Once the event is achieved, only one of the activities is initiated according to a random selection based upon the assigned probabilities. In this example, alternative $A_1$ will be selected 60 percent of the time, $A_2$ 30 percent of the time, and $A_3$ only 10 percent of the time. |
| TERM |  | Once the event is achieved, this output command serves to end the iteration. |

Table A.4 RISKNET Node Input/Output Rules (continued)

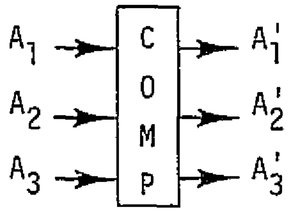
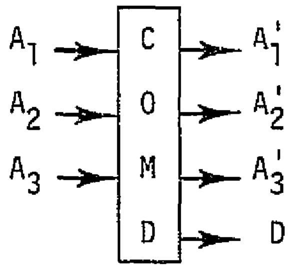
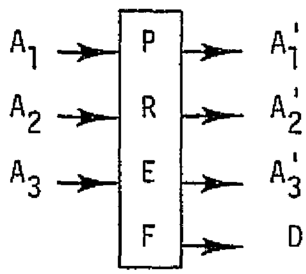
| Rule | Graphical Representation | Description |
|---|---|---|
| COMBINED: | | |
| COMP |  | The project event is achieved if and when the first of the input activities is successfully completed. Each input activity has a directly associated output activity. The first activity successfully completed initiates its corresponding output activity, and the remaining output activities are dropped. If $A_2$ is first in, then $A_2'$ goes out; and $A_1'$ and $A_3'$ are dropped. |
| COMD |  | The project event behaves just as the COMP event with the exception of the addition of a default (D) arc. If none of the input activities ($A_1$, $A_2$ nor $A_3$) are completed successfully, then arc D is initiated. |
| PREF |  | This project event has an associated output arc per input arc plus a default arc with input (output) preferences stated in order, $A_1$, $A_2$, and $A_3$. If the input corresponding to the preferred output is successfully achieved, the preferred arc is initiated. If this activity is unsuccessful, the node will proceed through the preference list waiting for the input corresponding to the next most preferred output. If an input corresponding to a lesser preferred output is achieved first, the node will wait for the completion of the input corresponding to the preferred output before proceeding. If none of the input arcs are successful, output arc default (D) will be initiated. |

Table A.5 RISKNET Input and Output Rule Codes

| Number | Input Rule | Output Rule |
|---|---|---|
| 1 | AND | ALL |
| 2 | OR | PROB |
| 4 | INIT* | TERM* |
| 5 | COMP | COMP |
| 6 | COMD | COMD |
| 7 | PREF | PREF |

*The above input rules numbered 1, 2, and 4 can be combined with any of the output rules of the same numbers with one exception. The input/output rule INIT/TERM (44) is obviously trivial and is therefore not to be considered.

Table A.6 RISKNET Arc Data Requirements

- The name of the arc.
- The name of the node that initiates the arc and the name of the node that completes the arc.
- The time distribution identifier (Refer to Table A.3).
- The parameter values for the time distribution (Refer to Table A.3).

Table A.7 Arc Format

| Field | Variable | Format | Description |
|---|---|---|---|
| 1 | Name | A4 | Name of Arc |
| 2 | From | A4 | Name of Originating Node |
| 3 | To | A4 | Name of Achievement node |
| 4 | Time Distribution | I1 | See Table A.3 |
| 5 | Probability Parameter I | F10.0 | For a Time Distribution requiring N Parameters, use Associated field(s).<br>N<br>1 —— 5<br>2 —— 5,6<br>3 —— 5,6,7 |
| 6 | Probability Parameter 2 | F10.0 | |
| 7 | Proability Parameter 3 | F10.0 | |
| 8 | Fixed Cost | F10.0 | Fixed Cost of each Activity |
| 9 | Variables | F10.0 | Variable Cost for Each Activity |
| 10 | Probability 1.0 | F10.0 | Probability of Activity completion once it has been initiated.* |

*The probability that the activity will be successfully completed, given that it is initiated, is usually set equal to 1.0; otherwise, there is the risk of never completing the project.

The user must provide the information listed in Table A.8 for each node, and Table A.9 gives the specific FORTRAN format for each node record. When a node is assigned a probabilistic output rule or any of the combined input/output rules, it requires a second record immediately following the first. The second node record of a probabilistic node indicates: 1) the number of arcs issuing from the node and 2) the name of each exiting arc immediately followed by its respective probability of initiating that arc. The second node record of the COMP rule indicates: 1) the number of input/output arc pairs and 2) the name of the entering arc followed immediately by the name of the associated exiting arc. The second node record for COMD and PREF rules differs only slightly from COMP due to the unpaired default arc exiting from the node. This arc is paired with an imaginary input arc called ZZZZ. The number of input/output arc pairs for the COMD and PREF corresponds to the number of output arcs, including the default. Table A.10 distinguishes the differences involved in the second node record for the four rules. Table A.11 illustrates examples of these four special nodes.

As can be seen from Table A.11, the COMD and PREF nodes are identical in appearance. Although their appearance is similar and their second node data records have identical formats, there is a major difference. A preference node has a well defined order of desired input activity completion regardless of completion time. The order in which the input arcs are listed on the second node data record determines the preference listing. The COMP and the COMD nodes initiate output activities on a "first in, first out" basis.

| Table A.8 RISKNET Node Data Requirements |
|---|
| • The name of the node.<br>• The input/output or combined rule associated with the node (See Table A.5).<br>• Additional information concerning successor activities of the node if it has the PROB or a combined output rule. |

Table A.9 RISKNET Node Format (Record #1)

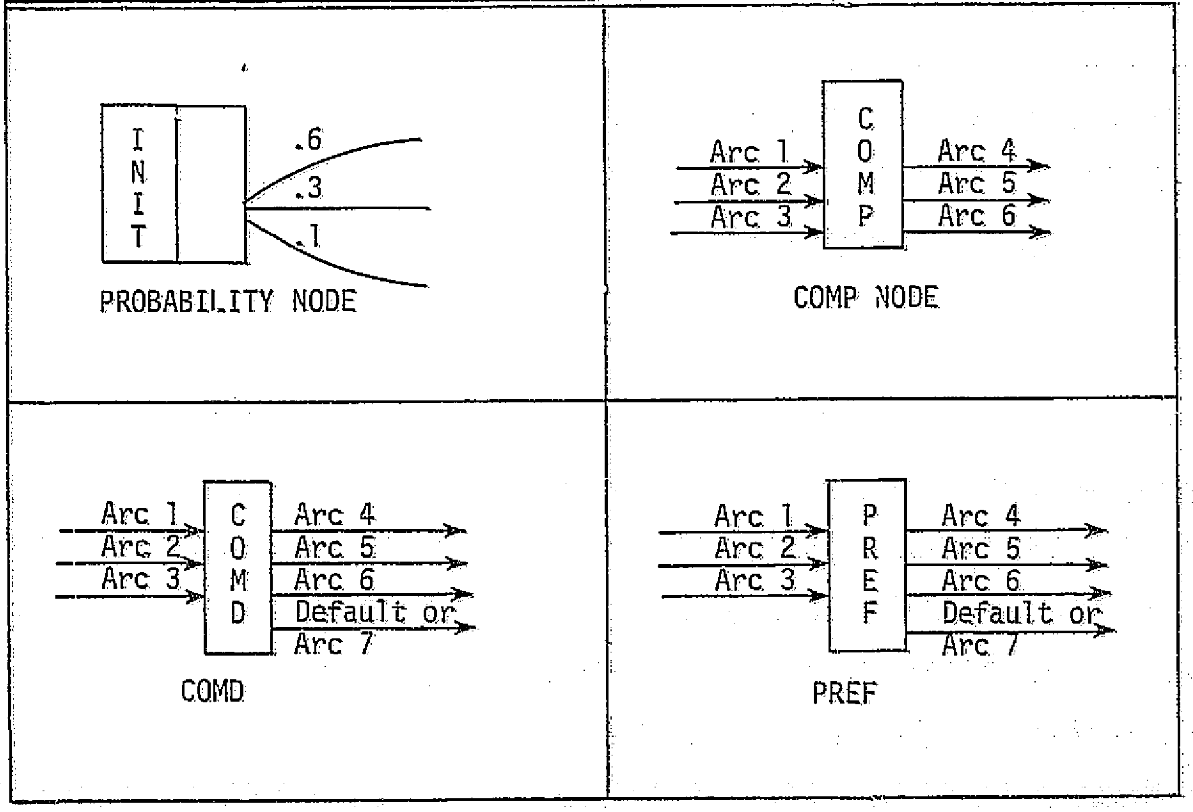
| Field | Description | Format |
|---|---|---|
| 1 | Name of Node | A4 |
| 2 | Input Rule | I1 |
| 3 | Output Rule | I1 |

Table A.10 RISKNET Node Format (Record #2)

| Output Rule | Field | Description | Format |
|---|---|---|---|
| Probability | 1 | Number of exiting arcs | I2 |
| | 2* | Name of arc | A4 |
| | 3* | Probability of arc | F6.3 |
| COMP | 1 | Number of arc pairs | I2 |
| | 2* | Name of input arc | A4 |
| | 3* | Name of output arc | A4 |
| COMD and PREF | 1 | Number of arc pairs | I2 |
| | 2* | Name of input arc | A4 |
| | 3* | Name of output arc | A4 |

*Fields 2 and 3 can be repeated all the way across the record. A maximum of seven arc names can appear on the probabilistic data record; and a maximum of nine can be fitted on the second record of COMP, COMD, and PREF nodes. Additional arcs must appear on subsequent records.

Table A.11 RISKNET Nodes Requiring Second Data Record



The first section of data records (the arc descriptions) is ended with a record containing only RETU, and the second group (the node descriptions) is ended by RETU and $END signifying the end of the job. A format summary of the entire data input section is given in Table A.12. The summary also designates the subroutine which reads in the particular data records.

A.3 A Sample Run on RISKNET

In order to illustrate all of the input and output files of RISKNET, an example was created with the intent to employ all of the possible variants of arc and node structures. Every node input/output rule, all time distributions, and many fixed and variable cost combinations have been used at least once. The network is presented in Figure A.1 with the arcs and nodes numbered. Table A.13 lists the arcs, their time distributions, their fixed cost, and their variable cost. As this example does not directly correspond to a real system, there are no descriptions of the activities. When dealing with an actual network, however, it is a good practice to create full arc description sheets which include the following information:

- Arc number
- Initiating node
- Completion node
- Time distribution and parameters
- Fixed and variable costs
- Description of the activity.

Figure A.2 is a listing of the data file for the example network with each line representing one data record. A run was made using the data file, and the results are presented in Figure A.3.

Table A.12 Summary of the RISKNET Data File Format

| Subroutine | Data Record Format | Description |
|---|---|---|
| REPID | RUNID (20A4) | Title can appear anywhere along 80 space record. |
| | ITER (I5) | Iteration number must be right justified in first 5 columns. |
| ARCIN | (3A4, I1, 6F10.0) | (Arc name, from node to node, time distribution, probability parameters, costs and probability of arc completion.) One of these records must be made for each arc. |
| | RETU | The arc section is ended by Return. |
| NODIN | (A4, I2) | (Node, input rule, output rule.) One of these records must be made for each node. |
| | (I2, 7(A4, F6.3)) | (Number of output arcs, arc names and associated probabilities.) This record is the second data record required only for probabilistic nodes. |
| | (I2, 20A4) | (Number of arc pairs, name of input arc, name of associated output arc.) This record is the second data record required for any of the combined rule nodes. For COMD and PREF, the default arc is paired with an imaginary input arc ZZZZ. |
| | RETU | The node section is ended by Return. |
| | $END | The entire data input is ended by $END. |

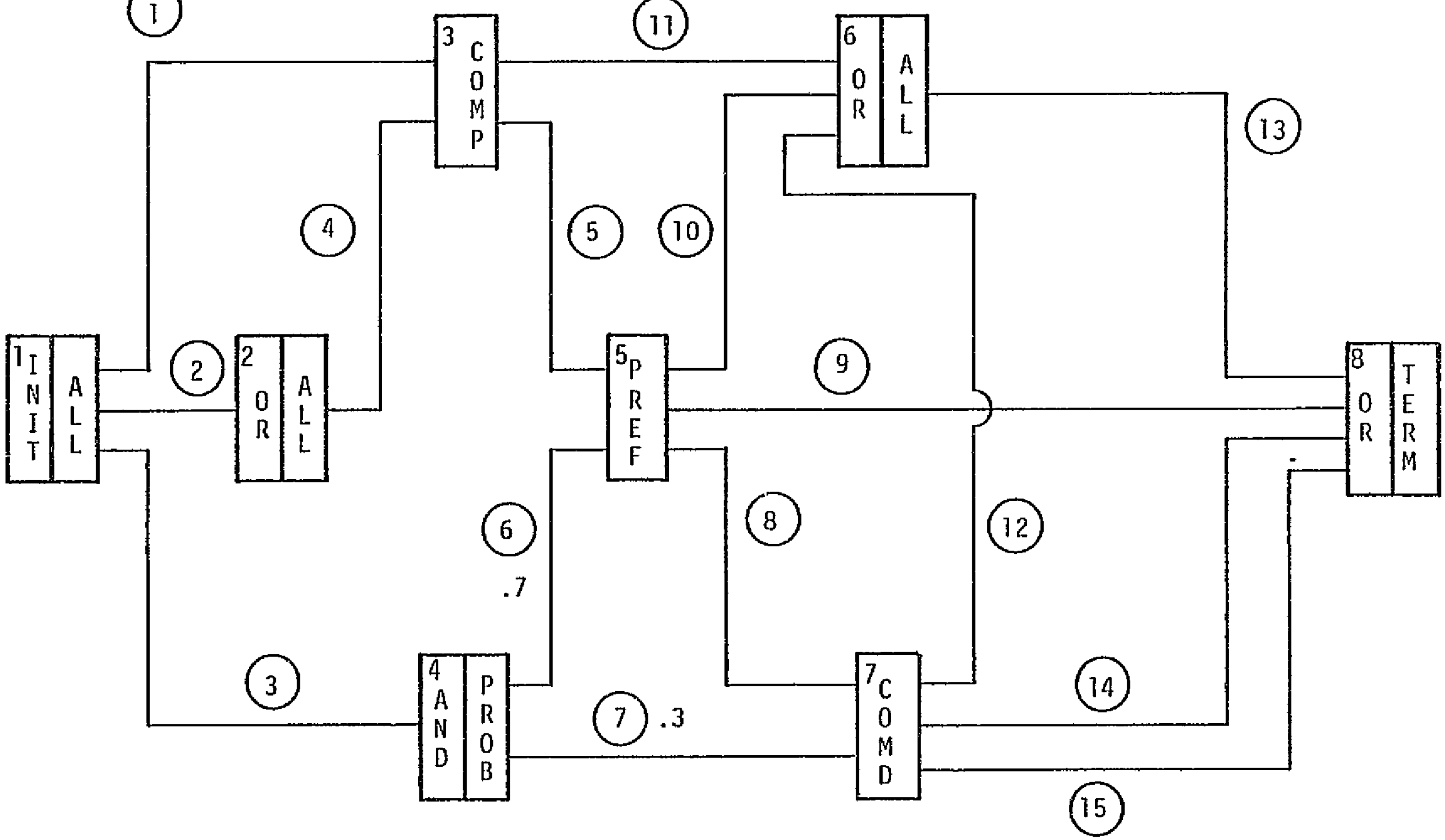



Figure A.1 A Sample Run Network

| Table A.13 Arc Statistics | | | | |
|---|---|---|---|---|
| Arc Number | Time Distribution and Identified | Probability Parameters | Fixed Cost | Variable Cost |
| 1 | Normal-1 | (5, 1) | 0. | 83. |
| 2 | Uniform-3 | (3, 6) | 58. | 122. |
| 3 | Constant-4 | (0) | 0. | 0. |
| 4 | Normal-1 | (4, 1) | 283. | 0. |
| 5 | Triangular-2 | (2, 5, 9) | 100. | 159. |
| 6 | Triangular-2 | (6, 7, 10) | 303. | 56. |
| 7 | Constant-4 | (5) | 244. | 0. |
| 8 | Uniform-3 | (7, 11) | 145. | 50. |
| 9 | Normal-1 | (8, 2) | 600. | 0. |
| 10 | Uniform-3 | (4, 6) | 0. | 0. |
| 11 | Normal-1 | (4, 2) | 500. | 0. |
| 12 | Constant-4 | (5) | 350. | 0. |
| 13 | Triangular-2 | (1, 5, 6) | 400. | 45. |
| 14 | Uniform-3 | (2, 8) | 30. | 100. |
| 15 | Uniform-3 | (3, 6) | 200. | 300. |

```
 200
A001N001N0031        5.     1.     0.      0.     83.     1.
A002N001N0023        3.     6.     0.     58.    122.     1.
A003N001N0044        0.     0.     0.      0.      0.     1.
A004N002N0031        4.     1.     0.    283.      0.     1.
A005N003N0052        2.     5.     9.    100.    159.     1.
A006N004N0052        6.     7.    10.    303.     56.     1.
A007N004N0074        5.     0.     0.    244.      0.     1.
A008N005N0073        7.    11.     0.    145.     50.     1.
A009N005N0081        8.     2.     0.    600.      0.     1.
A010N005N0063        4.     6.     0.      0.      0.     1.
A011N003N0061       12.     2.     0.    500.      0.     1.
A012N007N0064        5.     0.     0.    350.      0.     1.
A013N006N0082        1.     5.     6.    400.     45.     1.
A014N007N0083        2.     8.     0.     30.    100.     1.
A015N007N0083        3.     6.     0.    200.    300.     1.
RETU
N00141
N00221
N00355
02A001A011A004A005
N00412
02A006000.7A0070000.3
N00577
03A006A009A005A010ZZZZA008
N00621
N00766
03A007A014A008A012ZZZZA015
N00824
RETU
$END
```

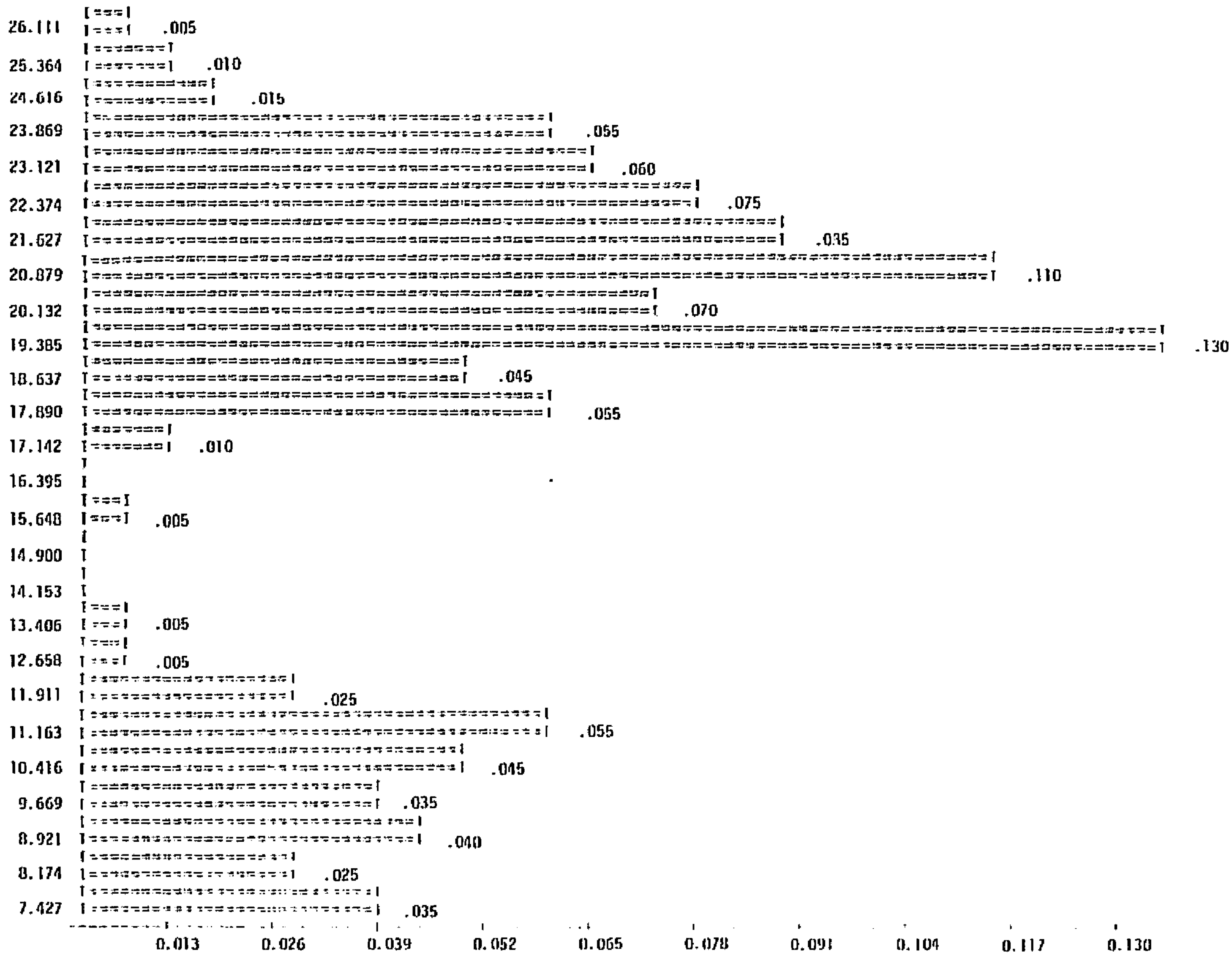
Figure A.2 Test Run on RISKNET

TEST RUN ON RISKNET
200 ITERATIONS

| ARC | INP NODE | OUT NODE | TIME DIST | ARG1 | ARG2 | ARG3 | COST | P OF COMP |
|---|---|---|---|---|---|---|---|---|
| A001 | N001 | N003 | NORM | 5.00 | 1.00 | 0.0 | 0.0 + 83.00 T | 1.00 |
| A002 | N001 | N002 | UNIF | 3.00 | 6.00 | 0.0 | 58.00 + 122.00 T | 1.00 |
| A003 | N001 | N004 | CON | 0.0 | 0.0 | 0.0 | 0.0 + 0.0 T | 1.00 |
| A004 | N002 | N003 | NORM | 4.00 | 1.00 | 0.0 | 283.00 + 0.0 T | 1.00 |
| A005 | N003 | N005 | TRI | 2.00 | 5.00 | 9.00 | 100.00 + 159.00 T | 1.00 |
| A006 | N004 | N005 | TRI | 6.00 | 7.00 | 10.00 | 303.00 + 56.00 T | 1.00 |
| A007 | N004 | N007 | CON | 5.00 | 0.0 | 0.0 | 244.00 + 0.0 T | 1.00 |
| A008 | N005 | N007 | UNIF | 7.00 | 11.00 | 0.0 | 145.00 + 50.00 T | 1.00 |
| A009 | N005 | N008 | NORM | 8.00 | 2.00 | 0.0 | 600.00 + 0.0 T | 1.00 |
| A010 | N005 | N006 | UNIF | 4.00 | 6.00 | 0.0 | 0.0 + 0.0 T | 1.00 |
| A011 | N003 | N006 | NORM | 12.00 | 2.00 | 0.0 | 500.00 + 0.0 T | 1.00 |
| A012 | N007 | N006 | CON | 5.00 | 0.0 | 0.0 | 350.00 + 0.0 T | 1.00 |
| A013 | N006 | N008 | TRI | 1.00 | 5.00 | 6.00 | 400.00 + 45.00 T | 1.00 |
| A014 | N007 | N008 | UNIF | 2.00 | 8.00 | 0.0 | 30.00 + 100.00 T | 1.00 |
| A015 | N007 | N008 | UNIF | 3.00 | 6.00 | 0.0 | 200.00 + 300.00 T | 1.00 |

| NODE | NO. OF INPUT ARCS | NO. OF OUTPUT ARCS | INPUT RULE | OUTPUT RULE |
|---|---|---|---|---|
| N001 | 0 | 3 | INIT | ALL |
| N003 | 2 | 2 | COMP | COMP |
| N002 | 1 | 1 | OR | ALL |
| N004 | 1 | 2 | AND | PROB |
| N005 | 3 | 3 | PREF | PREF |
| N007 | 3 | 3 | COMD | COMD |
| N008 | 4 | 0 | OR | TERM |
| N006 | 3 | 1 | OR | ALL |

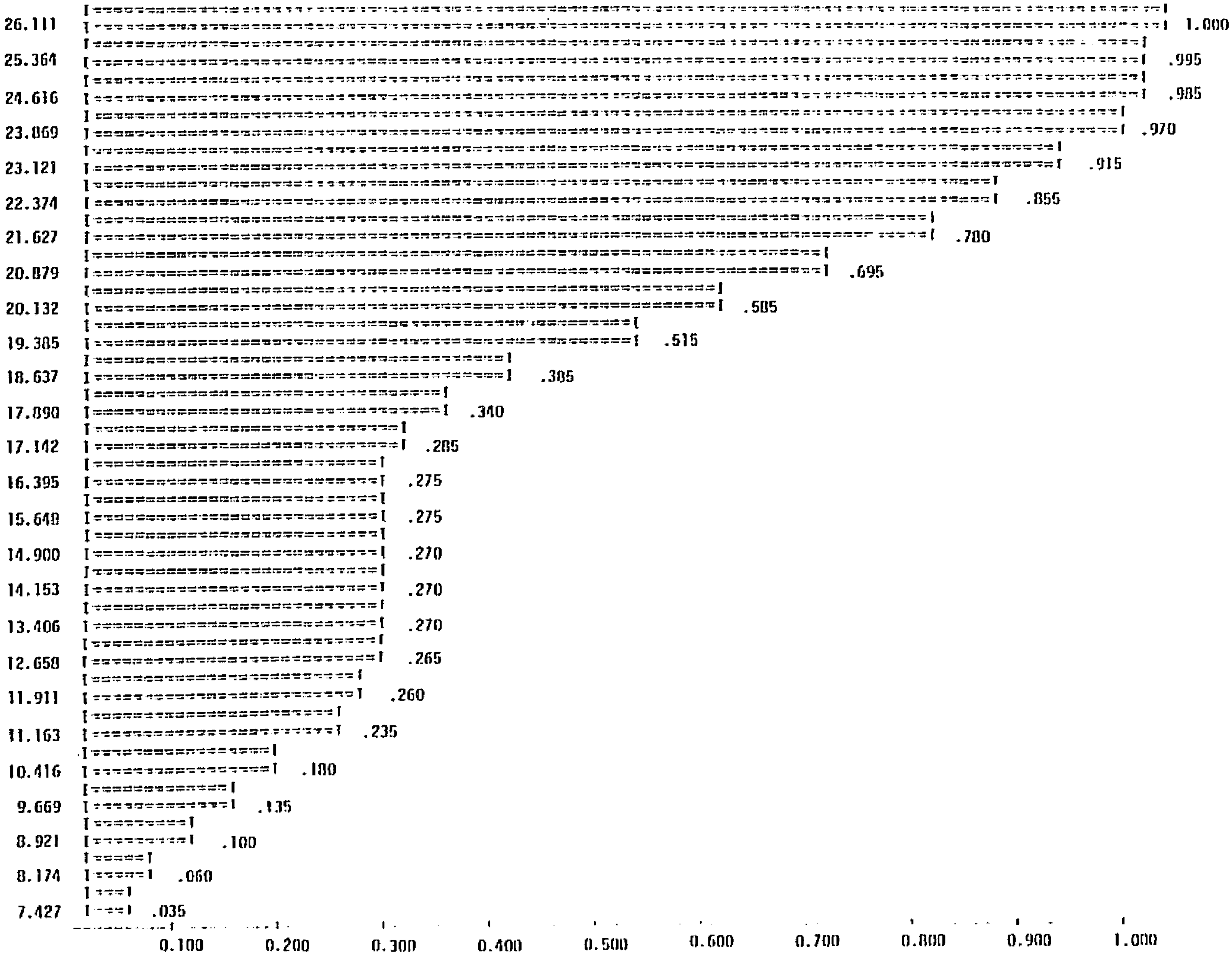
Figure A.3 Test Run on RISKNET




PROBABILITY DISTRIBUTION OF COMPLETION TIMES FOR TERMINAL NODE NOO8

MEAN = 18.294 VARIANCE = 27.973 STANDARD DEVIATION = 5.289

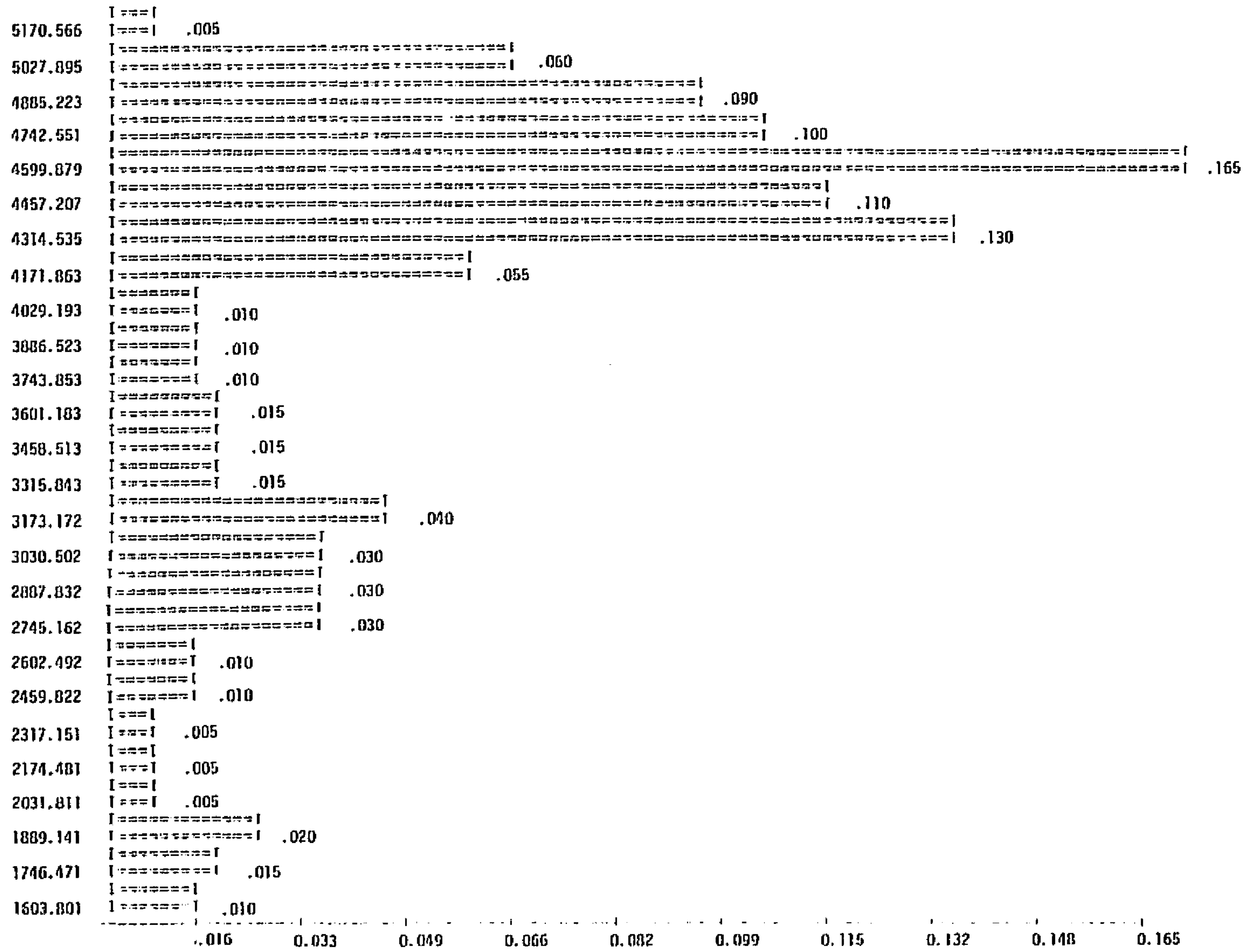
Figure A.3 Test Run on RISKNET (continued)




CUMULATIVE PROBABILITY DISTRIBUTION OF COMPLETION TIMES FOR TERMINAL NODE NOOB

MEAN = 18.294 VARIANCE = 27.973 STANDARD DEVIATION = 5.289

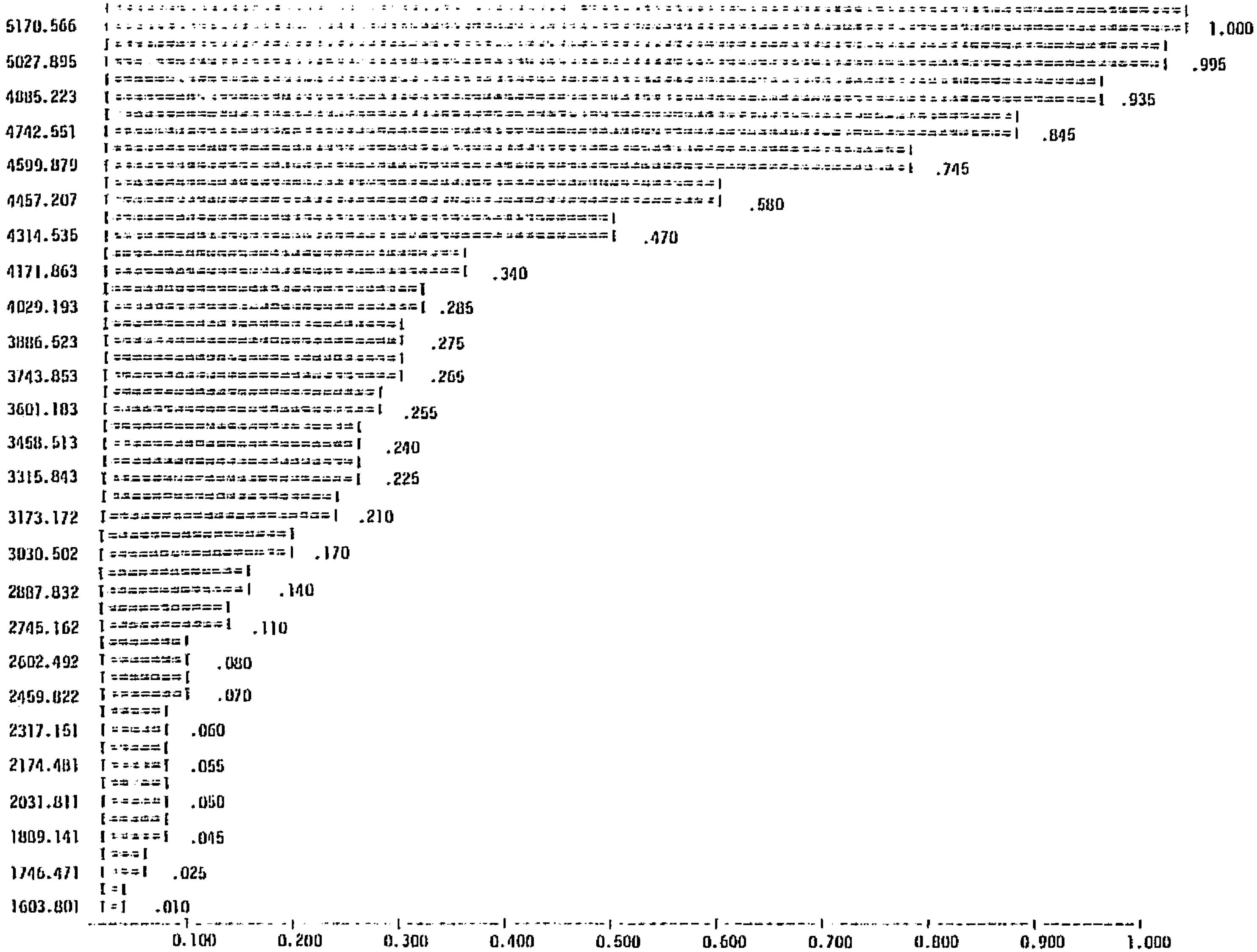
Figure A.3 Test Run on RISKNET (continued)




PROBABILITY DISTRIBUTION OF COMPLETION COSTS FOR TERMINAL NODE N008

MEAN = 4175.395 VARIANCE = 750682.812 STANDARD DEVIATION = 866.419

Figure A.3 Test Run on RISKNET (continued)




CUMULATIVE PROBABILITY DISTRIBUTION OF COMPLETION COSTS FOR TERMINAL NODE NOOB

MEAN = 4175.395 VARIANCE = 750682.812 STANDARD DEVIATION = 866.419

Figure A.3 Test Run on RISKNET (continued)

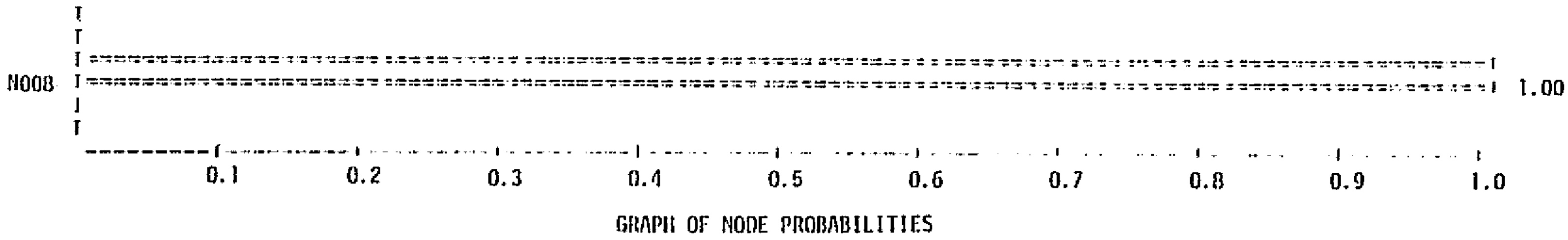



Figure A.3  Test Run on RISKNET (continued)