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AN INVESTIGATION OF TRANSITIONAL MANAGEMENT PROBLEMS FOR THE NSTS AT NASA

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QUARTERLY REPORT (JUL. 15, 1988 - OCT. 15, 1988)

BY

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DEPARTMENT OF INDUSTRIAL ENGINEERING
UNIVERSITY OF HOUSTON - UNIVERSITY PARK

OCTOBER 15, 1988

EXECUTIVE SUMMARY
AN INVESTIGATION OF TRANSITIONAL MANAGEMENT PROBLEMS FOR THE NSTS AT NASA
QUARTERLY REPORT (JULY 15, 1988 - OCT. 15, 1988)
JLH 24 OCT 88

This report contains a summary of the work effort of the University of Houston research team for the third quarter of effort in a yearly grant for the NSTS. As such is serves as a resting place for the ideas and concepts developed this quarter with the collaboration of the Management Integration Offices of NASA. Another objective of the report is found in the hope that the report will help to stimulate the healthy problem solving process already present at NASA. The main thrust of the contractual work is to help NASA to find ways and means of moving into a truly operational era with the shuttle program. This work is a continuation of early work and the reader is encouraged to read the final reports of earlier years.

Chapter One of the report is an introduction and contains much of the information in the preceding paragraph. Chapter Two deals with industrial adaptation and is in two parts: theory and application. In the theory section, impressions of the management system immediately after reflight are discussed. A key issue, in the author's opinion is the seeming lack of purpose of the program. The application section has six appendices: 1988 Demographic Survey, Field Notes of Interview with HL/P South Texas Nuclear Project, a comparison of the agenda's of the current manager with that of a previous manager, a note on compartmentalization to assist in manifesting, a study on launch prediction for STS-26, and a discussion of a statistical decision making course for upper level managers.

Chapter Three deals with theoretical results returned on flow shop scheduling which will be of use down stream to the program. Chapter Four deal with a statistical model developed to predict the flight rate in outlying years and indicates the program will have trouble making its desired rate. Chapter Five covers the contractual effort and shows the work to be on schedule.

TABLE OF CONTENTS

CHAPTER I

INTRODUCTION

I. INTRODUCTION

The intent of this report is to satisfy the contractual obligation of a quarterly report and to provide NASA with an interim overview of the results of the University of Houston team to date. Another objective of this report is to provide a resting place or summary document, if you will, for the ideas and concepts developed with the collaboration and support of the Management Integration Offices of NASA. In addition it is hoped that this report will help to stimulate the healthy problem solving process already present at NASA.

This report is the third quarterly report in the fourth year of the research contract. The main thrust of the work is to assist NSTS in finding ways and means of moving into a truly operational era in the sense of routine timely production of flights. This work is a continuation of the effort of the first three years. The reader who seeks a full understanding of the concepts presented is encouraged to read the final reports of the last three years.

1.0 STRATEGY AND FORMAT

The overall strategy of this effort is to 1) search the literature for applications of transition management and other related issues, 2) conduct investigations into the experiences of the industries with the transition management, and 3) to adapt the information found in 1) and 2) above into a form useful to NASA while at the same time applying industrial engineering and engineering management expertise to problems and issues as they emerge.

The strategy discussed above provides the format for the remaining parts of the report with the industrial adaptation being covered in Chapter II, a heuristic programming study of a flow shop with multiple processors contained in Chapter III, a report on the prediction of NSTS flight rate in Chapter IV, and the contractual effort being presented in Chapter V.

CHAPTER II

INDUSTRIAL ADAPTATION

APPENDICES:

II. INDUSTRIAL ADAPTATION: THEORY AND APPLICATION

1.0 THEORY

The single most important event of this quarter has been the resumption of flight with STS-26. The management system is still in a mode of coping with reflight issues and has not as of this time settled into the same routine business as usual format that was prevalent prior to Challenger. The impression of this observer is that top level management is getting on with the business of flight but still devotes a goodly amount of time to reflight issues. There are still numerous top level meetings demanding a large amount of executive time.

It is the impression of this observer that little, if any, significant change in the process has been made from the process used prior to Challenger. Some titles have been shifted, some work has been reorganized, but the bulk of the main product is still the same. Surely, in a product as complex as space flight, one does not expect to see significant change over a short time period. However, this coming quarter will demonstrate whether the organization has laid the groundwork to move forward or whether it reverts to the same difficult working environment that existed before Challenger.

What seems to be missing is the "grand vision", the purpose of the program. Where does the shuttle program fit in the overall plan of space exploration and in the goals and needs of the country? Where is the leadership and support necessary to move the program forward? In blunt terms, if the program has no idea, in the large sense, where it is supposed to be going, how can it hope to get there? Stated another way, how can the program decide if it is doing or has done a good job if there is confusion or ambiguity about what the job is? Perhaps these statements are too strong. Perhaps there exists a strategy for the program. However, one point is without question. The United States is in real danger of losing its lead in space. This danger will not be mitigated without a well thought out and thoroughly supported space program. At the current time, the shuttle program is the flagship of the space program. To move the country's space program forward, the shuttle program will require the best of strategies and the most substantial support that the country can provide.

2.0 APPLICATION

The annual demographic survey of the professional employees who support the shuttle program and from whom the leadership will be derived was completed this quarter. This survey is contained in Appendix II A. The work force is still old, experienced, highly graded, and educated. All of these factors, while necessary for R/D, will require modification before a truly operational program is in place.

Appendix II B deals with the second in a two part series of interviews with the South Texas Project of Houston

Lighting and Power. The South Texas Project is the nuclear facility of the power company. This interview was with operations manager of the facility. In this interview, the manager discusses, among other points, the importance of planning and the importance of developing an operational culture in making the move from design to operations.

In Appendix II C, a side by side comparison of the agenda analysis of the Deputy Director NSTS Program (1987) to that of the Manager NSTS Program (1984) is presented. This analysis seems to imply that the job is less independent than it once was. In other aspects, such as the temporal concentration on immediate issues, the job is much the same.

Appendix II D is a broadside dealing with considerations which need to be made before the flight rate can be increased. In this broadside, a plan is discussed to begin the standardization of shuttle flights.

An experiment in the use of statistics to determine the validity of opinion regarding the predicted launch date of STS-26 is presented in Appendix II E. The results of this experiment indicate that the sample chosen was relatively effective in predicting the date of launch.

Appendix II F contains the rationale and the first set of notes pertaining to a course designed to assist upper level managers in the use of statistics in decision making. This course is currently being taught at the upper levels of shuttle management.

APPENDIX II A

1988 DEMOGRAPHIC SURVEY

DEMOGRAPHIC SURVEY
C,D,E,F,G,S,T, AND V
ORGANIZATIONS
PROFESSIONAL EMPLOYEES
SUMMER 88
13 OCT JLH

INTRODUCTION AND OBJECTIVES:

This report is the first half of a two part report. The purpose of this half is to characterize as far as possible the makeup of the above offices regarding the age, grade, experience, starting age, and education of their professional employees. These offices were chosen to reflect the base which composes the current management and technical support for the shuttle program at JSC. The future needs of the program will also, more than likely, come from this base. As the shuttle flies again and becomes more stable on its path to a more operational era, human resource and manpower planning will be an essential ingredient in smoothing the transition. The intent of this document then, in simple terms, is to show the demographic state of NSTS and its support elements as of the summer of 1988.

As an aside, manpower planning for the shuttle is complicated by the fact that many of the upper level employees have been with NASA for long periods of time with a considerable number hiring on around the same point in time. Without careful planning, NASA could find itself stripped of upper level experience by both normal and early retirements over a short period of time.

This survey was also done in the summers of 84, 85, 86, and 87. **The second half of this report which follows at a later date, is a comparison of these different surveys.** Since the continuation of flight may prompt a series of retirements, a survey of this sort for next year is of particular importance. Since the planning changing of the demographics of an organization is a long lead time issue, a careful analysis of the demographic state and its trending seems to be necessary.

DEMOGRAPHICS:

The size of the sample in this survey was 1749. The rest of this report is devoted to a discussion of the charts presented.

AGE - CHARTS 1 AND 2

Chart 1 shows the age distribution in 5 year increments and is bimodal. The high point is the 46-50 year old bracket with a second peak at 26-30. This is different from what one expects with most organizations having a uni-modal distribution with a single peak at a younger age. This is however the typical JSC plot. The 46-50 peak is particularly bothersome since many of these people are approaching, if not already at, early retirement age. This will cause significant problems at some point in time, if for no other reason, that this group will reach retirement age at roughly the same time. This problem has the potential to become critical within the next several years.

Chart 2 shows the average age by grade and the average age (42.84 years) for all employees surveyed. For the predominant grades of 13 through SES there is approximately 4 years difference between the 13's and the 15's (46.4 to 50.3) and about 6 years between the 13's and the SES's (46.4 to 52.9). A significant dip occurs with the 12's through the 7's (34.3 to 26.0).

GRADE - CHART 3

Chart 3 shows the number by grade. The following is a percentage breakdown of the figures:

GD	SES	15	14	13	12	11	9	7	TOTAL
%	1.4	11.8	20.4	34.9	14.9	8.8	6.1	1.8	100.1
CUM%	1.4	13.2	33.6	68.5	83.4	92.2	98.3	100.1	

As a rough approximation, 1/3 of the employees are 14 or above, 1/3 are 13's, and 1/3 are 12 or less. Two problems surface as a result of these first 3 charts. One is that 1/3 of the employees are 14 or above and about 1/2 are 46 or older, directing attention to the retirement problem discussed earlier. Another is that the large number of high ranks may make promotion problems for the younger employees.

SERVICE - CHART 4

This chart shows the average years of service by grade. The 13 through 15 grades are essentially flat (18.4 through 21.8) with a small rise in service for SES (24.9). As would be expected, the 12 through 7 grades have appreciably less service. The average service for the sample was 15.7 years.

START AGE - CHARTS 5 AND 6

Chart 5 shows the start age for two year increments and Chart 6 shows the average start age for grade. Chart 5 illustrates that most people came to work for NASA in their 20's and Chart 6 shows that this property is fairly uniform throughout the grades.

COMBINED DEMOGRAPHICS - CHART 7

Chart 7 shows the age, service, and start age as a function of the grade. It is a summary of several of the preceding charts.

HIGHEST DEGREE - CHARTS 8, 9, AND 10

Highest degree refers to the highest degree earned. In this and all other degree comments, the doctors degree includes Ph.D.'s, M.D.'s, and D.D.S's.

Chart 8 shows the level of the highest degree with 69% BS, 20% MS, 9% DOC, and 3% with no degree. So 29% of the sample has a graduate degree indicating that the work force is highly educated.

Chart 9 shows the field and level of the highest degree with the largest component being a BS in engineering. Chart 10 shows the field of the highest degree with engineering comprising more than half of the degrees.

BS AS HIGHEST DEGREE - CHARTS 11 AND 12

For the employees for which the BS was the highest degree, Charts 11 and 12 show the field. Of the 1200 in the survey with a bachelors, engineering had 834 or 67%.

MS AS HIGHEST DEGREE - CHARTS 13 AND 14

These charts are similar to the two preceding except they show the information for the masters degree. Of the 347 masters degrees in the survey, engineering had 180 or 52% of the sample.

DOCTORS DEGREE - CHARTS 15 AND 16

Of the 152 doctors degrees, science was the largest with 102 (only 24 of which were in medicine) or 67%. Engineering was second largest with 30 or 20%.

FIELD AND LEVEL OF HIGHEST DEGREE □ CHART 17

This chart is a composite chart of several which preceded it and shows the field and level of the highest degree.

CONCLUSIONS:

The work force is old, experienced, high graded, and educated. All of these factors, while being necessary for R/D, will require extensive modeling before the shuttle can comfortably exist in an operational environment. While the key players for an operational era will certainly be pulled from the group and the operational era must be designed by this group, it is hard to imagine a worse demographic make up for an on going operational program.

Other problems already discussed but worthy of managerial attention include the retirement problem and the high number of employees with grade 14 or better. Both of these problems need to be monitored on an annual basis.

AGE DISTRIBUTION
SUMMER 1988

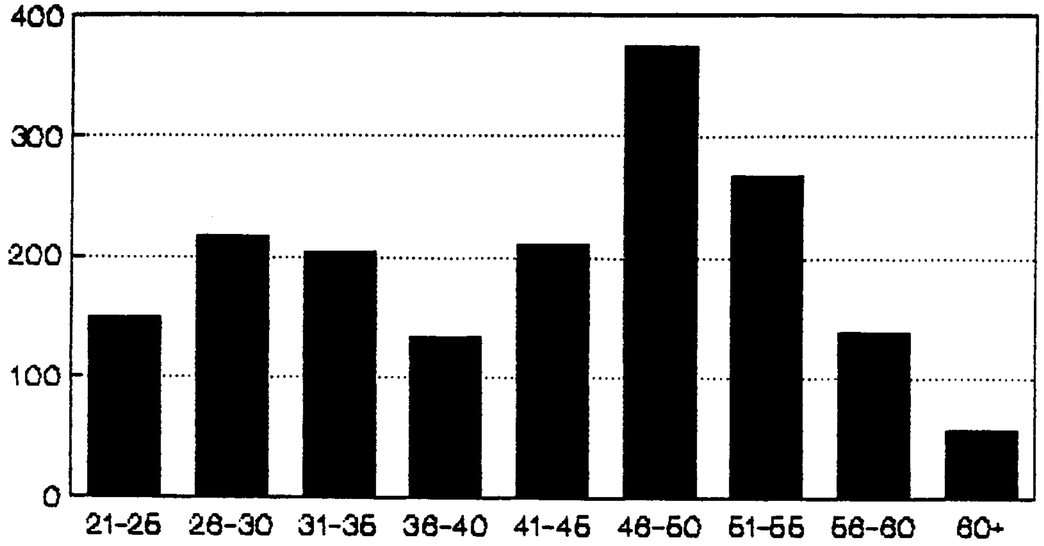

CHART 1

AVERAGE AGE BY GS
SUMMER 88

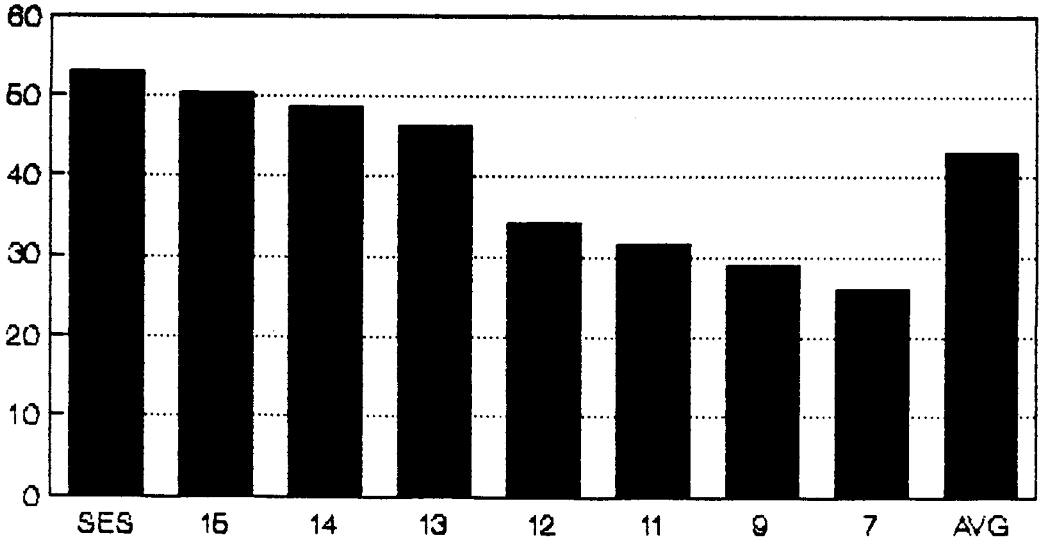

CHART 2

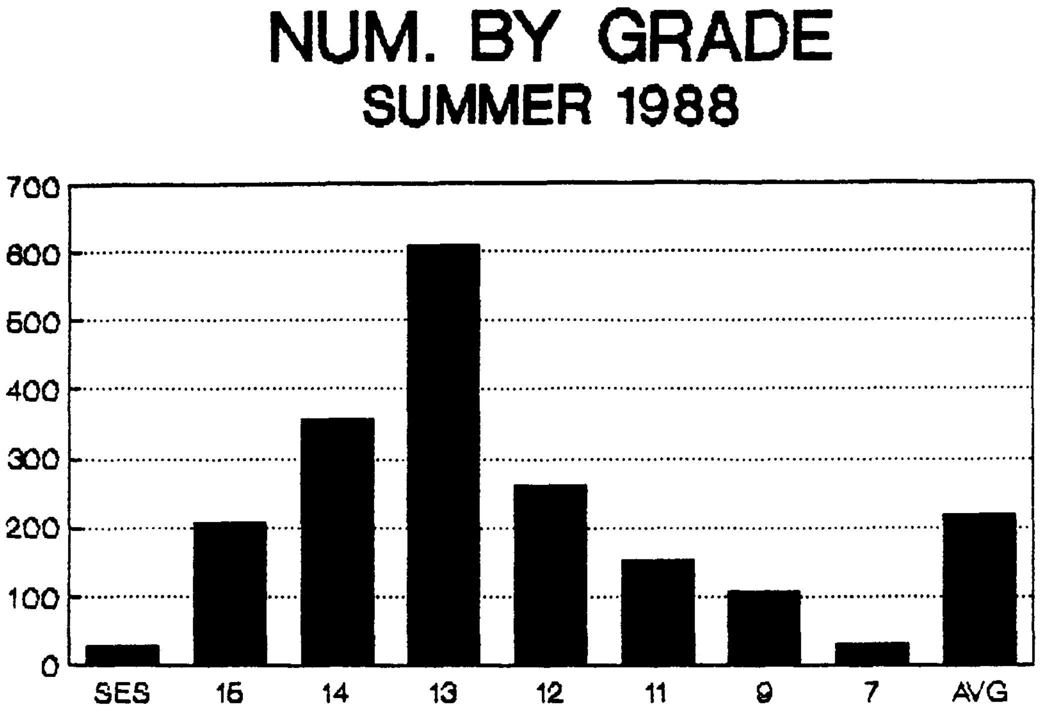

CHART 3

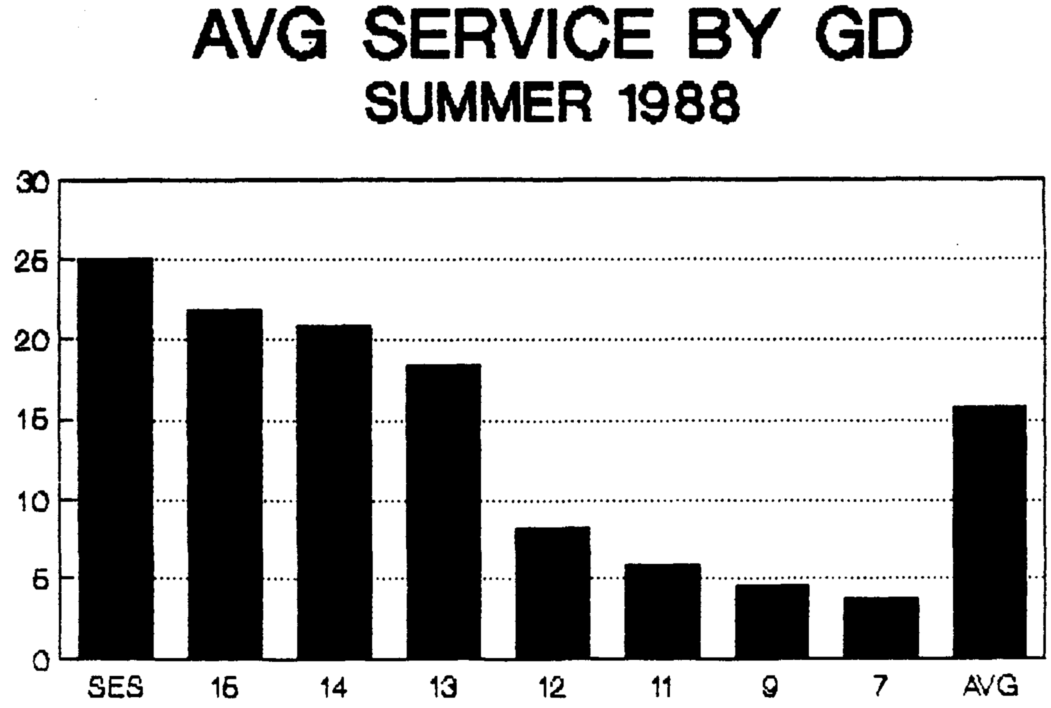

CHART 4

START AGE
SUMMER 1988

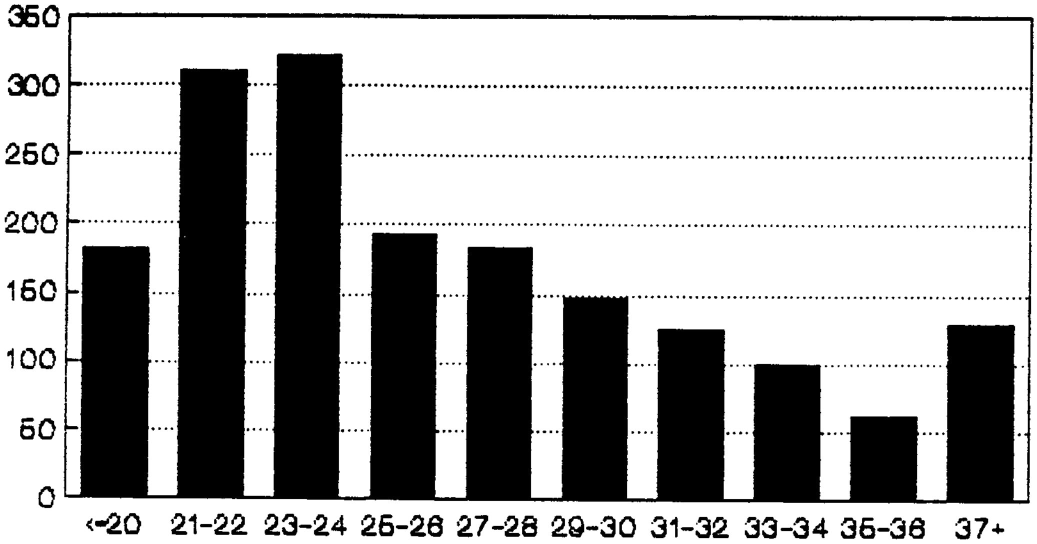

CHART 5

AVG START AGE
SUMMER 1988

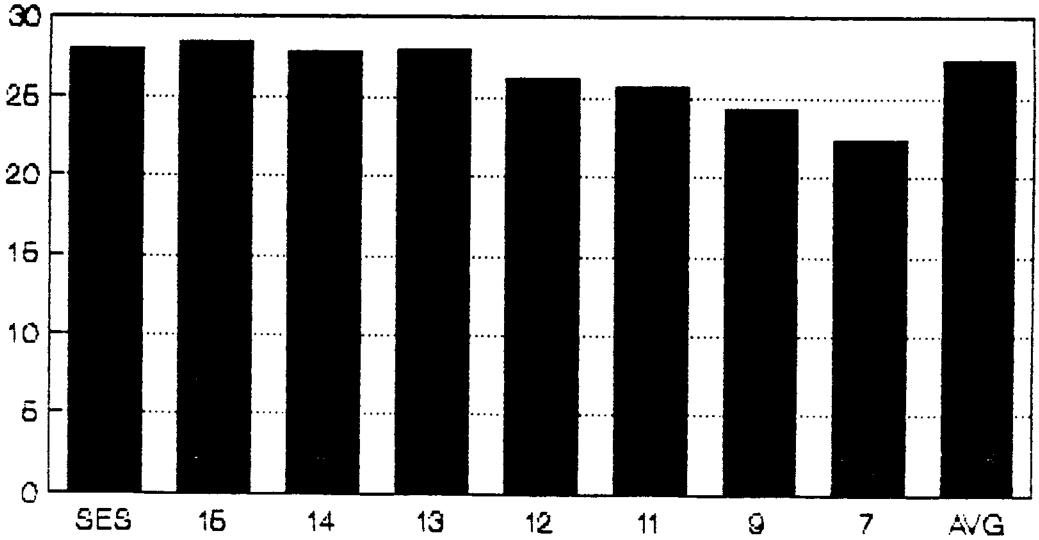

CHART 6

AGE/SERVICE/START AGE/GD
SUMMER 1988

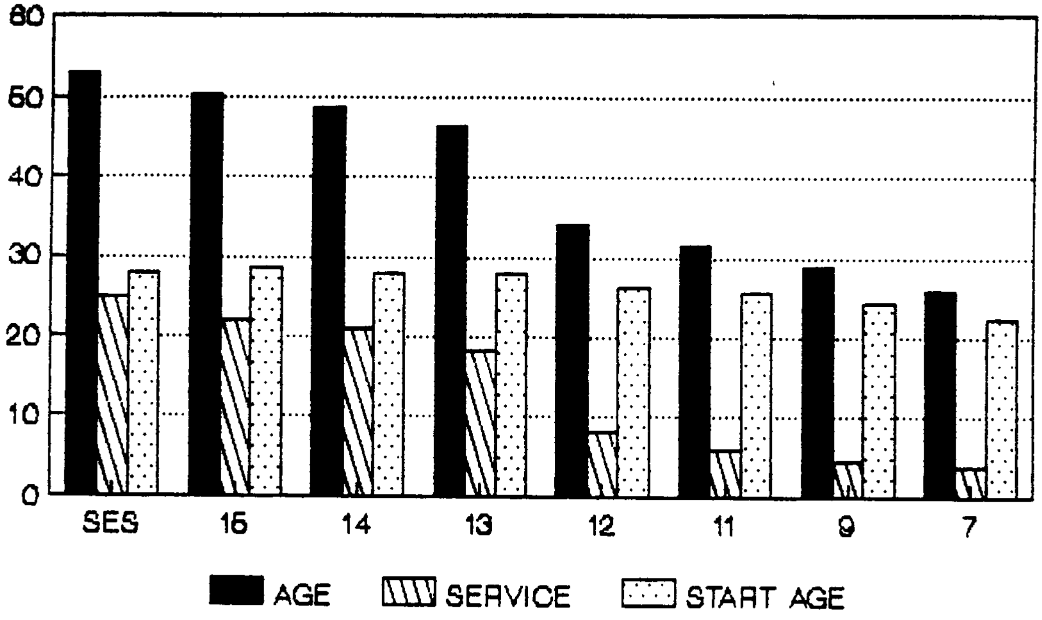

CHART 7

HIGHEST DEGREE LEVEL
SUMMER 1988

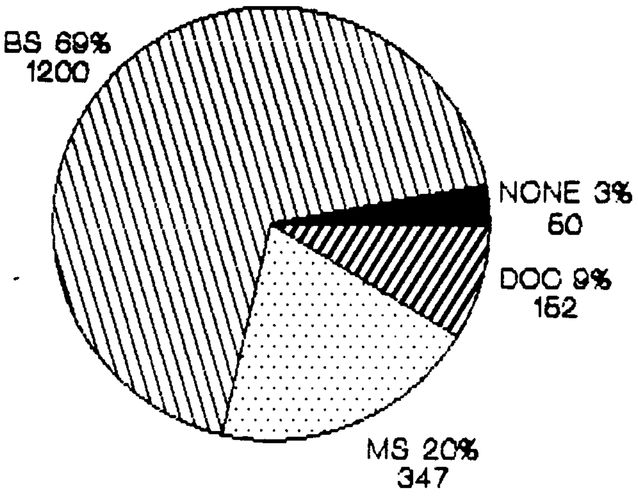

CHART 8

FIELD OF HIGHEST DEGREE
SUMMER 1988

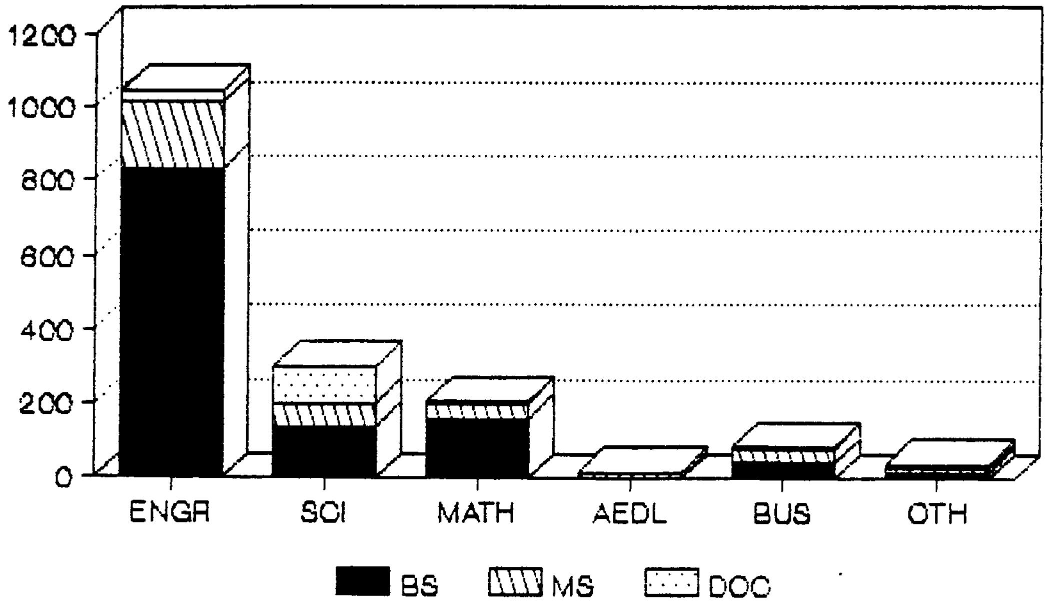

CHART 9

FIELD OF HIGHEST DEGREE
SUMMER 1988

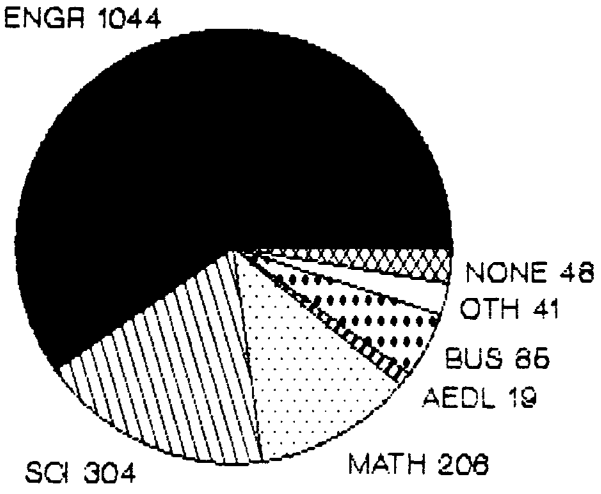

CHART 10

FIELD OF BS DEGREE
AS HIGH DEGREE
SUMMER 1988

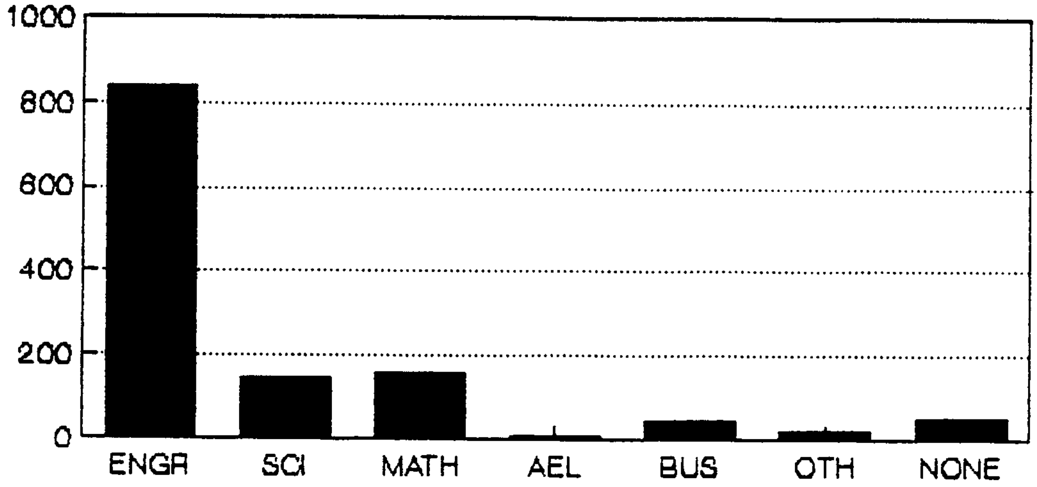

CHART 11

FIELD OF BS DEGREE
AS HIGH DEGREE
SUMMER 1988

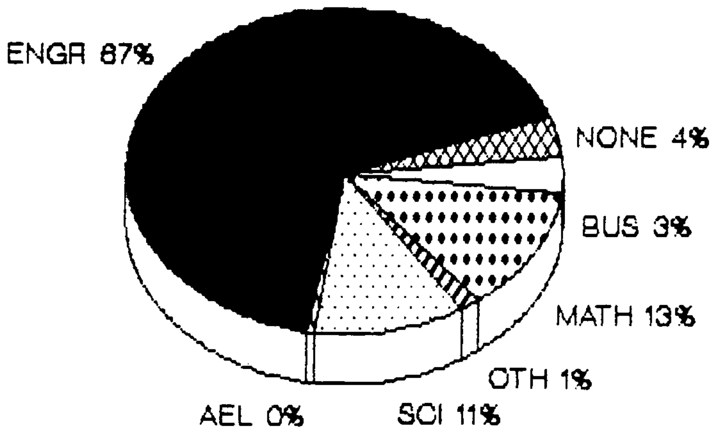

CHART 12

FIELD OF MS DEGREE
AS HIGH DEGREE
SUMMER 1988

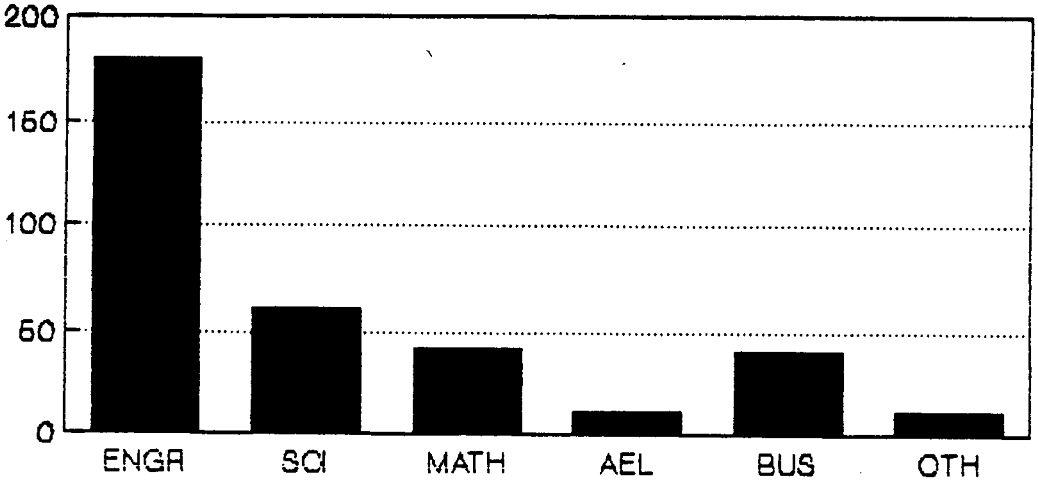

CHART 13

FIELD OF MS DEGREE
AS HIGH DEGREE
SUMMER 1988

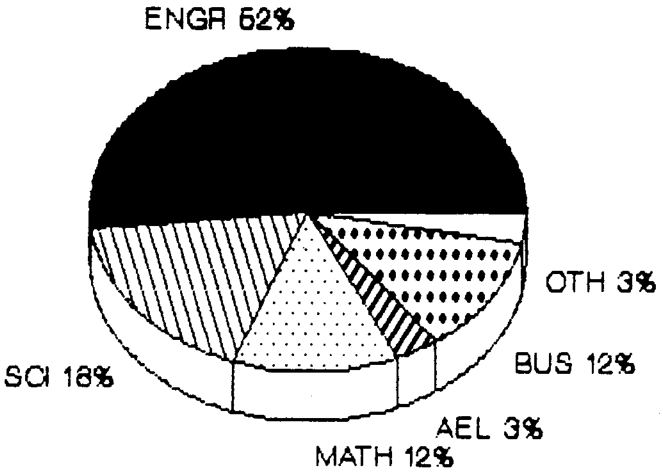

CHART 14

FIELD OF DOCTOR'S DEG
AS HIGH DEGREE
SUMMER 1988

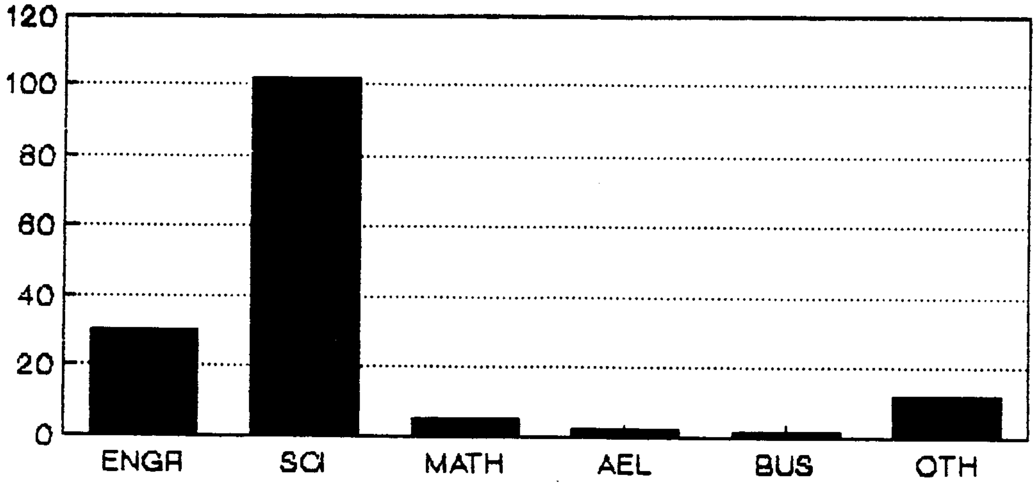

CHART 16

FIELD OF DOCTOR'S DEG
AS HIGH DEGREE
SUMMER 1988

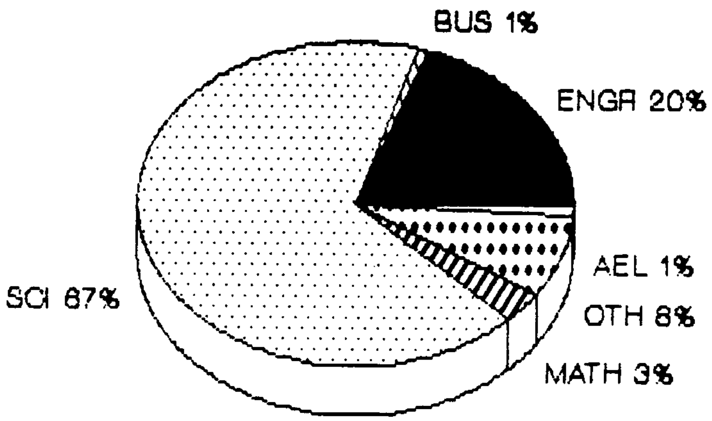

CHART 16

DEGREES BY FIELD
AND LEVEL
SUMMER 1988

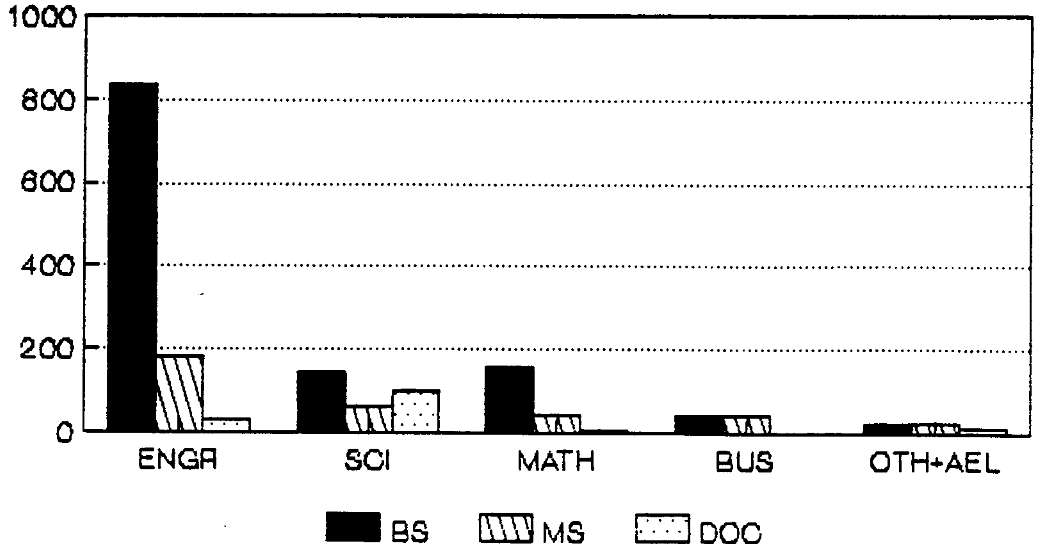

CHART 17

APPENDIX II B

FIELD NOTES OF INTERVIEW WITH HL/P

SOUTH TEXAS NUCLEAR PROJECT (STNP)

FIELD NOTES
INTERVIEW WITH GERALD D. VAUGHN
VP NUCLEAR OPERATIONS - HL/P
SOUTH TEXAS NUCLEAR PROJECT
ON 5 AUGUST 88
JLH 9 AUGUST 88

1. Attending the meeting were J.L.Hunsucker and R. Sitton from the University of Houston and G. Vaughn from STNP/HLP. Vaughn is an electrical engineer with previous experience in nuclear operations with another power company.
2. STNP currently has one reactor on line and is trying to bring the other one up. They are having some start up problems with the one which is up. The plant is currently undergoing a change from the design/construction phase to the operational one.
3. HL/P has had some significant problems with the STNP and, in addition, has received some bad press because of the plant.
4. In considering design changes, the initial input would probably come from the operational side of the house. Regardless of origin, the first step is to go to ops for a cost justification before going to engineering to determine technical factors of the proposed change. Then the change is sent to a combined committee of ops and design to be decided on.
5. In this change committee, safety is used as a shield to defend the need for a proposed change. The only protection against this shield of safety is a strong comprehensive criterion list which includes other factors and which must be met.
6. A culture needs to be built for the change committee. One important aspect of the culture for going to operations is standardization. If you change one, you should change them all.
7. The very first step in going from design/construction to operations is to decide on priorities. At STNP they are:
   a) safety b) reliability of product c) people management d) cost effectiveness e) public/community interfaces.

(See exhibit B of attachment "South Texas Project Electric Generating Station Master Operating Plan included at the back.)

8. Once priorities are established, they must be used by all subgroups in bringing about the change.
9. A necessary step in going to operations is to define an operations culture. The priorities mentioned above are one of the initial steps in establishing this culture. Note that the operations culture is very much different from the R/D construction culture.
10. STNP is heading toward being self sufficient from the contractor/vendor groups.
11. As a part of the culture, the degree of self

sufficiency must be defined.

12. To be cost effective, the degree of sub contract involvement must be reduced.

13. As a control move, contractors are handled by a different group than operations.

14. The intent is to use special contractors for complex tasks but to do day to day work in house.

15. Vaughn has a "plan of the day" meeting for 1/2 hour each morning. In this meeting they discuss the last 24 hours and the next 24 hours. He purposefully does not chair the meeting but attends. He will meet with selected individuals immediately after the meeting to discuss special topics which the meeting touched on.

16. Vaughn seeks out problems by going to meetings such as the one above and by going out into the plant.

17. As part of the culture, he has informed managers, either in writing or orally, what he wants to be kept informed of and what types of items he should be immediately notified of.

18. After I described the seal problem with the shuttle to him, he said he felt that this type of problem would probably not be stopped at STNP and probably would not be stopped with the shuttle. The reason for this is that sub managers have to be given some autonomy in decision making on complex projects. Top management cannot decide everything.

19. They have a program called the Safe Team Group. This is an independent high level review which anyone can access. It is designed particularly for those concerns on which an employee cannot get managerial attention.

20. He personally meets with each new employee, usually in a group format, and covers: a) the Safe Team Group b) standards and long term objectives c) strategies to be used d) management priorities e) professionalism.

21. Some of his employees, at all levels, have moved from the R/D-constructor side of the house to the operational side.

22. They have made safety an important part of the operational culture.

23. It takes an individual with a technical background to do his job. He estimates that some 40% of his job is technical.

24. He spends a goodly amount of time on setting objectives and standards and on deciding where the plant should go. Even this requires a technical background.

25. He estimates that 25-30% of his job is looking forward, 40-45% is today oriented, and 25% is looking backward.

26. He spends a goodly amount of time setting 5 year plans.

27. He has just finished the process of developing a master operating plan (see attachment). A plan of this type, in some form, has to be developed and well defined in order to go operational. While he used subordinates to help with the plan he did the major work.

28. Every goal in the plan has a goal champion who is a key manager but not on the executive committee.

29. They have a succession planning program with a developmental aspect.

30. In the succession plan, they take the top jobs and list the characteristics. These then are priortised for necessity to do the job. Then two or three candidates are identified for each position and assessed. A developmental plan is then devised for each candidate. This developmental plan is very broad based and includes cross training, sometimes outside the company.

31. HL/P takes an aggressive posture in public relations. They take the offensive whenever possible. One of their goals in the public relations program is to insure that their integrity is beyond reproach.

32. In their transition management, they used a blend of the hand over team and the parallel track team approaches.

33. As operations grows, research shrinks, even in the budget. This is very hard for the design group to accept.

34. As an aside, since May, the word "nuclear" has been removed from all references to the plant. The project is now called the "South Texas Project". The plant is now called the "South Texas Project Electric Generating Station". This action extends to the signs around the plant and to the visitor center.

ATTACHMENTS:

SOUTH TEXAS PROJECT ELECTRIC GENERATING STATION MASTER OPERATING PLAN

ORGANIZATION CHARTS: NUCLEAR GROUP ORGANIZATION
NUCLEAR PLANT OPERATIONS DEPARTMENT

INTERDEPARTMENTAL PROCEDURES STATION PROBLEM REPORTING

SOUTH TEXAS PROJECT ELECTRIC GENERATING STATION

MASTER OPERATING PLAN

DESCRIPTION

The Master Operating Plan for the South Texas Project Electric Generating Station integrates the efforts of all nuclear departments in the achievement of operating objectives and goals.

The Master Operating Plan is a rolling, five-year plan providing detailed information for the current and next year and general information for other years. In the process of developing the Plan, the following will be accomplished:

- Establishment of annual goals which support the Corporate goals and ensure the long term safety, reliability and efficiency of STPEGS;
- Identification of major work activities required to accomplish the annual goals, and the milestone actions associated with these activities;
- Development of an integrated schedule for major activities; and
- Establishment of the work scope to be included in budgets.

The Master Operating Plan integrates the activities of all departments which directly support the South Texas Project Electric Generating Station.

An Executive Committee, with representation from selected groups, is responsible for generating the Master Operating Plan. Direct responsibility for providing input recommendations, monitoring and reporting progress, and coordination of improvement activities will be delegated to specific managers accountable for the respective areas.

STPEGS Performance Indicators will be utilized to track monthly progress for selected goals.

CONTENTS

The Master Operating Plan will be contained in a workbook composed of the following sections:

Section I: Introduction - this contains an overall explanation of the Master Operating Plan, including contents, responsibilities, and administration.

Section II: Objectives and Strategies - this includes a copy of the following documents:

- Corporate Objectives and Strategies
- Nuclear Mission Statement (to be developed)
- STPEGS Long Term Objectives
- Nuclear Management Priorities

Section III - Goals - this contains the goals which direct the activities of the South Texas Project Electric Generating Station:

A. Corporate Goals - these top down goals set priorities for the overall company and establish standards of performance for the coming year. STPEGS Goals will be established to support the Corporate Goals.

B. STPEGS Goals - these are set each year to ensure continuously improving performance to reach the level of excellence identified in the long term objectives. There are two categories of STPEGS goals:

1. Standing Goals - the Master Operating Plan establishes the following standing goals for STPEGS. Each year the target levels may change, but the goal statements will remain the same.

a. Quality of Nuclear Operations - taken collectively, the following industry "Overall Performance Indicators" (INPO) are indicative of the quality of operations of a nuclear station:

- Equivalent Availability Factor
- Unplanned Automatic SCRAMS While Critical
- Unplanned Safety System Actuations
- Forced Outage Rate
- Thermal Performance
- Fuel Reliability
- Collective Radiation Exposure
- Volume of Low-Level Solid Radioactive Waste
- Industrial Safety Lost Time Accident Rate
- Safety System Performance

Performance targets will be established for each of these indicators to ensure STPEGS achieves a quality of nuclear operations above industry "median" values. Each indicator will have five year targets established on one sheet with the next year's target prominently displayed.

b. Regulatory Compliance - these goals help STPEGS achieve a high level of compliance to regulatory requirements. Five year performance goals will be established for each of the following:

- NRC SALP Rating - goals will be set to progressively improve the SALP rating for STPEGS until the long term objective to have the best rating in Region IV is achieved.

- NRC Violation Index - this goal will establish an annual limit for the number of points per NRC inspection. Points will be awarded according to the following schedule:

  Level III with Civil Penalty - 50 pts
  Level III without Civil Penalty - 30 pts
  Level IV Violation - 20 pts
  Level V Violation - 10 pts
  No Level I or II Violations

- Environmental Exceedances - this goal sets progressively lower target levels for the number of Exceedances of STPEGS environmental permits, until the long term objective to be considered a leader in environmental protection is achieved.

c. Employee Relations - these goals will require implementation of the necessary actions to achieve the STPEGS long term objective to be considered an excellent and safe place to work by employees. Specific goals will be established, and typically would include:

- Educational and Career Development - implementation of accredited training programs, implementation of a Management/Supervisory training program, implementation of a job rotation program, etc.

- Human Resources Management - maintain high employee morale and productivity, control of staffing and overtime, Focus Group participation, etc.

d. Financial Management - the overall purpose of these goals is to minimize costs to the ratepayer and ensure a reasonable return on investment to the company's owners. These include:

- Operations and Maintenance Budget
- Capital Budget
- Nuclear Fuels Budget
- Cost per net kilowatt-hour

2. Other Goals - these generally are not recurrent for more than 1 or 2 years. Input for these goals will come from the "bottom up" through the management chain and be presented early in the goal development cycle to the Executive Committee. Where appropriate, goals will be recommended for inclusion as Corporate level goals for the coming year.

Section IV - Master Schedules - identify major activities and events for management awareness and planning purposes.

(A) Schedules will be provided for the current and next year and will include such items as:

- refueling outages
- scheduled equipment outages
- scheduled audits (i.e., INPO, NRC, ANI, Major NA Audits, etc.)
- testing milestones for Unit 2
- major work activities which cross department boundaries may be identified on the schedule if requested by the Executive Committee

(B) A five year generation schedule will be provided, which identifies scheduled refueling and equipment outages and other known items of significant impact.

(C) A one-page listing of those known or anticipated major items which impact the Master Operating Plan for the years beyond the five year period will be maintained as the last part of this segment.

Section V - Budget - this section contains a copy of the following approved budgets for the current year:

- Operations and Maintenance
- Capital
- Nuclear Fuels

Monthly reports of budget performance will be included in this section.

Section VI - Performance Indicators - this section contains the latest monthly issue of the STPEGS Performance Indicators.

RESPONSIBILITIES

I. Executive Committee - has overall responsibility for administration of the Master Operating Plan. Membership is determined by the Nuclear Group Vice President and will consist of selected leaders from the major groups at STPEGS.

Responsibilities include:

- Establish STPEGS goals on an annual basis for the coming year. This includes setting one-year and five year performance targets for standing goals.
- Recommend goals for inclusion as Corporate level goals where appropriate.
- Designate a Goal Champion for each goal.
- Review and approve Goal Achievement Plans.
- Review and approve the preliminary budget for STPEGS prior to submission to the Nuclear Group Vice President.
- Monitor progress toward goal achievement, budget expenditures and schedule performance on a quarterly basis, and identify appropriate recovery actions if required.

II. Goal Champions - each goal will have a champion who will coordinate the efforts toward goal achievement. The champion will be designated by the Executive Committee and will normally be the department level manager of the area most related to the goal.

Responsibilities include:

- Recommend the performance target for the assigned goal to the Executive Committee each year including projections suggested for the next 4 years.
- Develop the Goal Achievement Plan. This involves direct interface with supporting departments to identify those activities required to achieve the goal. Milestone dates and budget estimates are obtained through feedback from the assigned department and this data is included in the Plan.
- Present the Goal Achievement Plan to the Executive Committee for approval each year. This includes explanation of how supporting department level activities combine to ensure the goal is met.

- Monitor progress toward goal achievement and identify problems to the Executive Committee as they arise. From information provided by supporting Department Managers, provide a status report on the Goal Achievement Plan for the Executive Committee's consideration at each quarterly meeting.

III. <u>Department Managers</u> - implement the supporting activities required to achieve established STPEGS goals. Department Managers are the key to the successful implementation of The Master Operating Plan.

Responsibilities include:

- Recommend STPEGS goals and proposed Corporate level goals to the Executive Committee based upon input from all levels within the department.
- Provide input and recommendations to the Goals Champions regarding supporting activities to achieve established goals for the preliminary Goal Achievement Plan.
- Develop internal action plans to ensure assigned support activities are accomplished and obtain management approval.
- Provide milestone dates and budget estimates to the Goals champions for inclusion in the final Goal Achievement Plan.
- Develop Department budgets using approved Goal Achievement Plan budget estimates as an input.
- Implement necessary actions to achieve successful completion of assigned support activities on time and within budget.
- Provide Goals Champions with periodic (at least quarterly) updates of the status of assigned support activities.
- Disseminate information concerning STPEGS goals and assigned department supporting activities to all employees in the department. Provide periodic status reports.

IV. <u>All Employees</u> - the Master operating Plan defines the course and destination for STPEGS. All employees must be familiar with the plan and actively support its successful implementation.

Responsibilities include:

- Recommend new or revised STPEGS goals to the Executive Committee via the management chain. Recommendations for Corporate level goals should also be identified.
- Maintain an awareness of goal status.
- Execute required support activities as established by the Plan.

ADMINISTRATION

The process for establishing STPEGS' goals and implementing the Master Operating Plan is summarized in chronological order below:

January

- Master Operating Plan Quarterly Meeting - the Executive Committee receives an update of goal status, schedule performance, and budget expenditures for the past year.

March

- Input received from lowest levels of the plant organization and relayed through the management chain regarding recommended new goals for the next year. The Executive Committee members bring recommendations to the Committee for consideration.
- Executive Committee considers recommendations and identifies STPEGS goals for the next year and assigns Goal Champions. Where appropriate, goals will be recommended for inclusion as Corporate level goals for the coming year.

April

- Master Operating Plan Quarterly Meeting - the Executive Committee receives an update on goal status, schedule performance, and budget expenditures for the current year, and identifies appropriate recovery actions if required.
- Goal Champions commence development of performance targets and preliminary Goal Achievement Plans. This involves direct interface with affected Department Managers to identify supporting activities required to achieve the goals.

May

- Goal Champions present performance targets and preliminary Goal Achievement Plans to the Committee for approval. These identify Department level supporting activities and assign responsibility.
- Executive Committee - meets with Department Managers and above, as a group, to promulgate the approved goals and preliminary Goal Achievement Plans, provide background for goal selection and performance targets established, and provide clarification as required.
- Department Managers commence development of internal action plans to accomplish the assigned activities, work with the Goal Champion on milestone dates and budget estimates.

June

o Department Managers obtain action plan approval through the management chain and convey final milestone dates and budget estimates to the Goal Champion for inclusion in the final Goal Achievement Plan.

o Goal Champions - send the final Goal Achievement Plan to the Executive Committee for approval when satisfied that department level supporting activities and milestone dates are adequate to achieve the goal. This final Plan also identifies budget estimates for each supporting activity.

o June 30 (latest) - Executive Committee approves the final Goal Achievement Plans, and authorizes the required funding to be included in preliminary budgets. Department level budget preparation commences.

July

o Master Operating Plan Quarterly Meeting - the Executive Committee receives an update on goal status, schedule performance, and budget expenditures for the current year, and identifies appropriate recovery actions if required.

o Department budgets are prepared and presented through the management chain for approval.

August

o The Executive Committee reviews the Master Schedule of activities and next year's preliminary budget.

October

o Master Operating Plan Quarterly Meeting - the Executive Committee receives an update on goal status, schedule performance, and budget expenditures for the current year, and identifies appropriate recovery actions if required.

December

o Master Operating Plan for the next year is distributed to appropriate management.

ATTACHMENT A

Section III. Goals

Goal Champions:

B.1.a Quality of Nuclear Operations

- Equivalent Availability Factor - M. R. Wisenburg
- Unplanned Automatic Scrams While Critical - J. W. Loesch
- Unplanned Safety System Actuations - J. W. Loesch
- Forced Outage Rate - Maintenance Manager
- Thermal Performance - J. J. Nesrsta
- Fuel Reliability - D. J. Denver
- Collective Radiation Exposure - J. R. Lovell
- Volume of Low-Level Solid Radioactive Waste - J. R. Lovell
- Industrial Safety Lost Time Accident Rate - J. W. Odom
- Safety System Performance - (Later)

B.1.b. Regulatory Compliance:

- NRC SALP Rating - M. A. McBurnett
- NRC Violation Index - M. A. McBurnett
- Environmental Exceedances - J. R. Lovell

B.1.c. Employee Relations: J. W. Odom

B.1.d. Financial Management:

- Operations and Maintenance Budget - D. O. Wohleber
- Capital Budget - D. O. Wohleber
- Nuclear Fuel Budget - R. J. Worden
- Cost per net Kilowatt-hour - J. M. Price

Section IV Master Schedules

Coordinator - W. L. Mutz

Section V Budget

Coordinator - D. O. Wohleber

Section VI Performance Indicators

Coordinator - W. L. Mutz

MASTER OPERATING PLAN COORDINATOR - J. M. PRICE

000001 (08/88) SOUTH TEXAS PROJECT ELECTRIC GENERATING STATION

ATTACHMENT B

MASTER OPERATING PLAN

GOAL ACHIEVEMENT PLAN

GOAL

GOAL CHAMPION:

STEP #	ACTION STEPS	RESPONSIBLE INDIVIDUAL	TARGET DATE	BUDGET ESTIMATE

EXHIBIT A

SOUTH TEXAS PROJECT ELECTRIC GENERATING STATION

LONG TERM OBJECTIVES

1. To achieve **excellent station** rating from INPO.
2. To achieve the best **NRC SALP rating average** in Region IV.
3. To be considered an **excellent** and **safe** place to work by employees.
4. To achieve **below average cost per net kwh** produced when compared to similar nuclear plants.
5. To be considered a **leader in environmental protection.**
6. To be recognized as a **leader in citizenship and service** to the community.

Exhibit B

SOUTH TEXAS PROJECT ELECTRIC GENERATING STATION

NUCLEAR OPERATIONS

MANAGEMENT RESPONSIBILITIES

I. Safety of the Public and Station Employees

- Safe Operations
- Releases to the Environment Well Below Limits
- Personnel Radiation Exposure ALARA
- Emergency Preparedness
- Industrial Safety
- Security

II. Reliability of Service

- High Availability and Capacity Factors
- Low Forced Outage Rates
- Necessary Capacity Additions on Schedule
- High State of Material Condition

III. People Management

- Open Management Style, Mutual Respect and Trust
- Employee Training and Career Development
- Positive Employee Relations
- Professionalism
- Teamwork

IV. Efficiency/Cost Effectiveness

- Organization
- Planning and Scheduling
- Budgets and Cost Control
- Productivity
- Heat Rates
- Cost Per Net KWH

V. Community and Industry Support

- Positive Community Relations
- Civic and Charitable Activities
- Industry Group Involvement
- "Sister" Utility Support

HOUSTON LIGHTING & POWER
NUCLEAR GROUP ORGANIZATION

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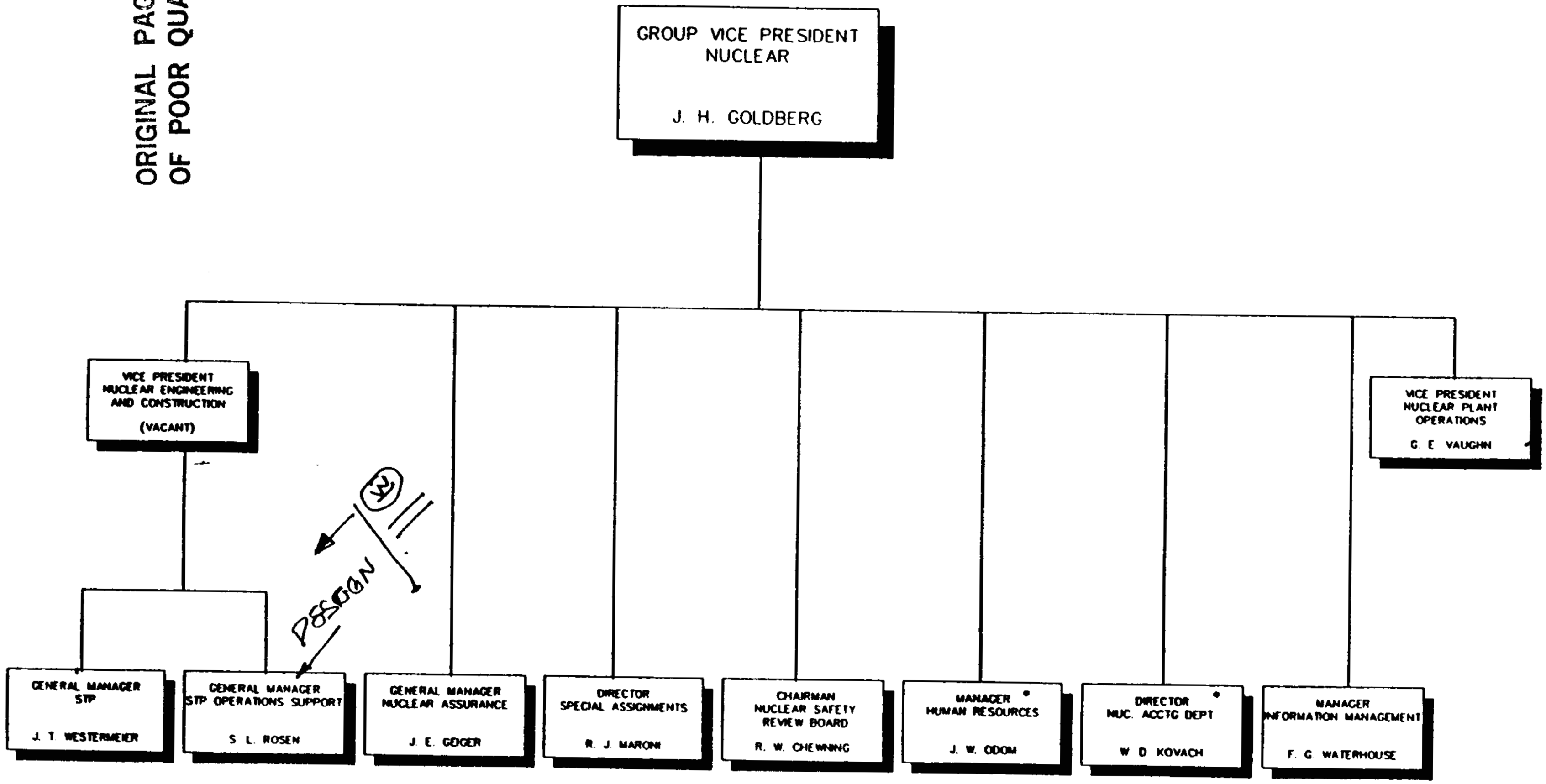

• MATRIXED

EFFECTIVE DATE
APRIL, 1988

NTG-0119

HOUSTON LIGHTING & POWER COMPANY
NUCLEAR PLANT OPERATIONS DEPARTMENT

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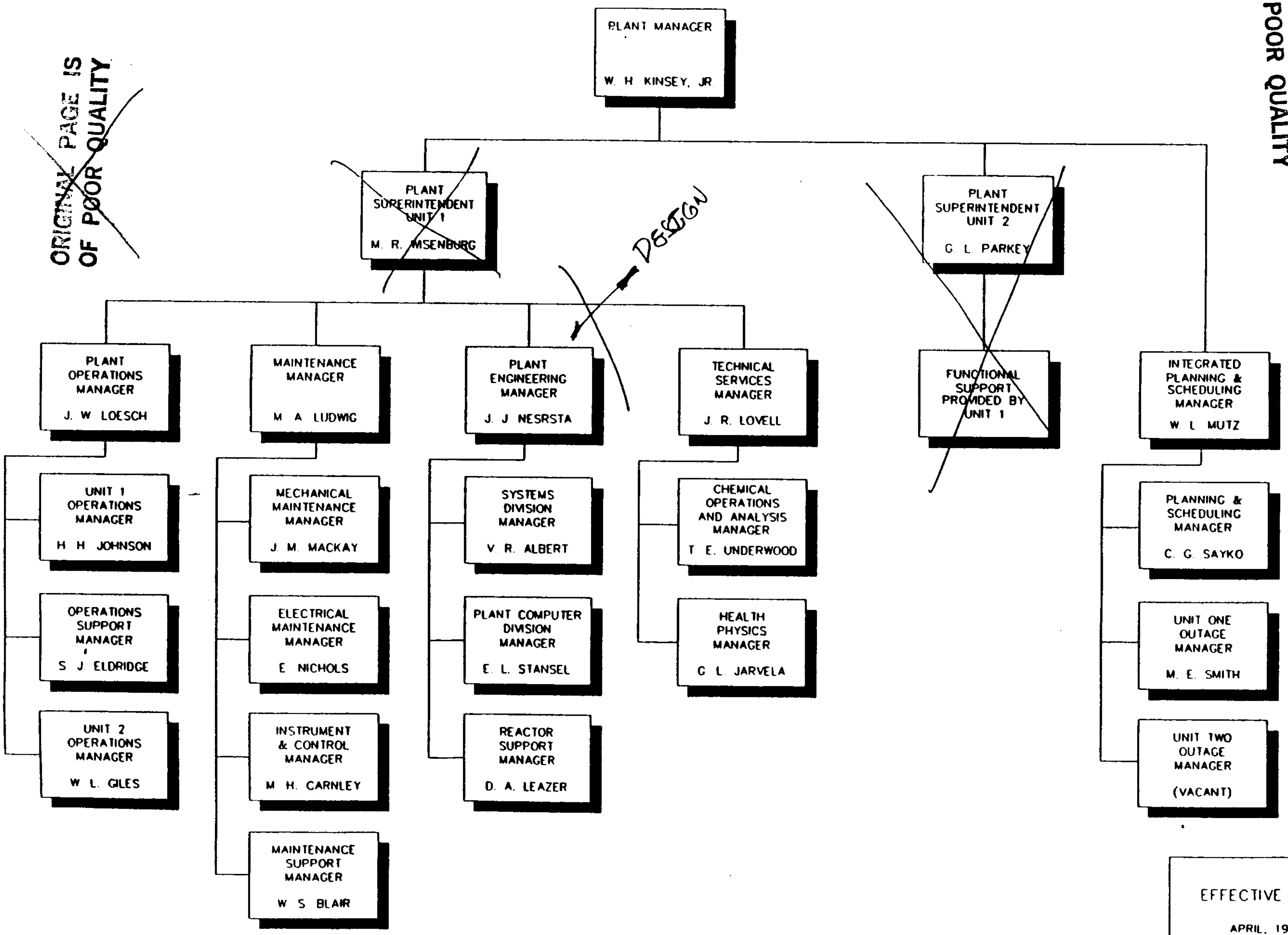


EFFECTIVE DATE
APRIL, 1988

NTC-0120

A SUMMARY OF THE
SOUTH TEXAS PROJECT ELECTRIC GENERATING STATION
INTERDEPARTMENTAL PROCEDURES
STATION PROBLEM REPORTING DOCUMENT

The South Texas Project Electric Generating Station Interdepartmental Procedure is a seventy-two page document that establishes uniform requirements for the management and administrative controls for identifying and correcting conditions that may not conform to established requirements and may impact the safe and reliable operation of the plant. Responsibilities are assigned to identify, initiate, evaluate, analyze, and document the above conditions when discovered by South Texas Project personnel.

The procedure applies to all South Texas Project personnel and all South Texas Project departments for reporting conditions that may not conform to established requirements and may impact the safe and reliable operation of the plant. Any South Texas Project employee may initiate a Problem Report in accordance with this procedure.

The Station Problem Reporting Procedure is intended to document and provide for management review of problems which meet predetermined reporting criteria. Other applicable reporting mechanisms should be used in lieu of this procedure if the predetermined criteria are not met. Also, the Station Problem Reporting Procedure does not replace the Nonconformance Report or Deficiency Report procedures.

APPENDIX II C

AGENDA COMPARISON OF 1987 NSTS PROGRAM DEPUTY DIRECTOR TO THE 1984 NSTS PROGRAM MANAGER

AGENDA COMPARISON
DEPUTY DIRECTOR NSTS PROGRAM 1987
TO
MANAGER, NSTS PROGRAM 1984

BACKGROUND: In 1985 an agenda analysis was done on the Manager of the NSTS Program Office using his 1984 agenda. Since that time the title of the office has changed to Deputy Director NSTS Program and the management structure has changed somewhat. In 1988 an equivalent analysis was done on the agenda of the Deputy Director NSTS Program using his 1987 agenda. The charts presented at the end contains a side by side comparison of these two tasks. Care should be taken in forming too strong an opinion from this data due to the subjective nature of categorizing the meetings.

RESULTS: RK spends about 20% as much time working across as GL but 170% as much time down and 190% as much time up. Regarding the time frame, the majority of the time, by a significant percent, in both case was spent with current matters with trace elements of the future and almost no time was spent on the past. In the location category, the DOD time essentially disappeared. RK spent more time with HQ and NASA other and less time with JSC and other than did GL. In the subject category, management time was halved and technical time doubled from 1984 to 1987. Budget time grew and personal time shrinked.

COMMENTS: A few very tentative conclusions can be reached from the data. One is that the job now is, to some degree, less independent than it was in the past. A goodly portion of time is currently spent with upper management and less time across. Another conclusion is that the job, in some sense, has become more technically oriented.

In many ways the job is unchanged. The Program Office is still a "now" organization with little time spent on the future and virtually no time spent looking backwards. Budget and personal subjects are still far behind management and technical issues.

LEVEL
NUMBER OF MEETINGS

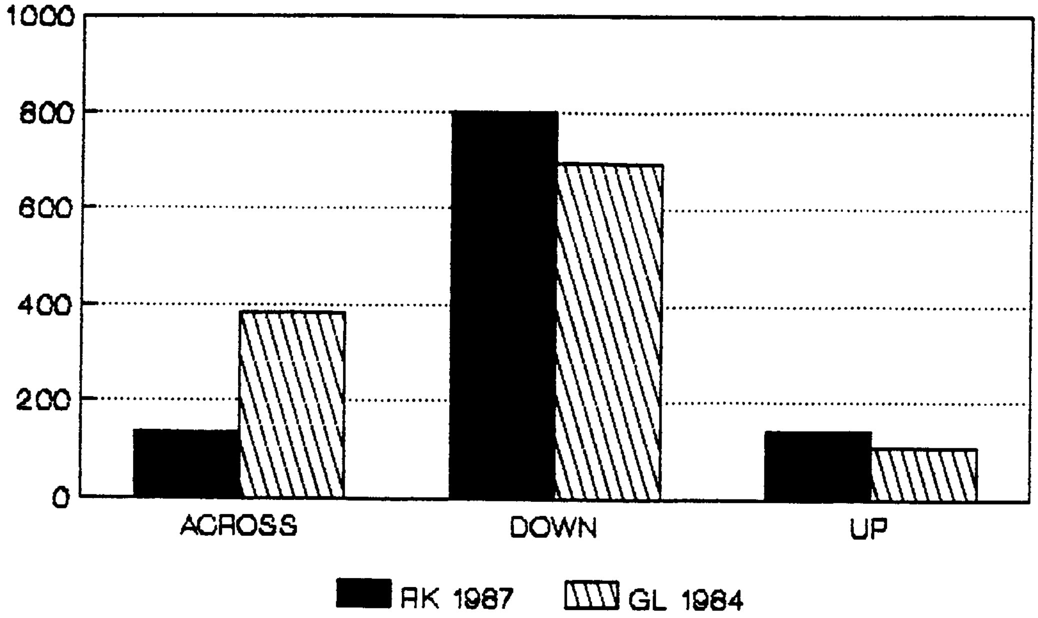


CHART 1

TIME OF MEETINGS

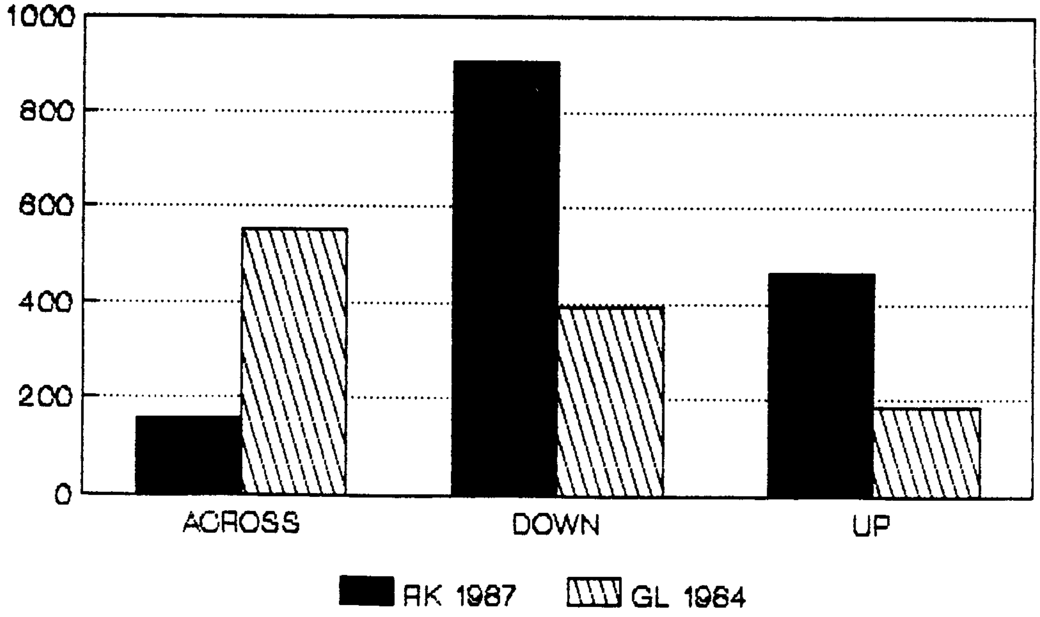


CHART 2

TIME FRAME
NUMBER OF MEETINGS

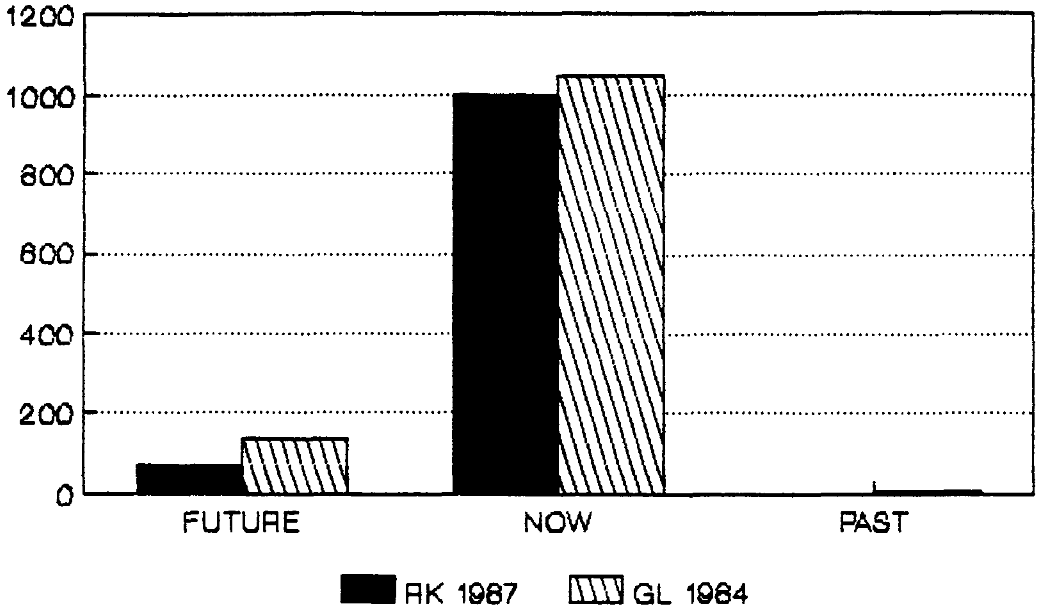


CHART 3

TIME OF MEETINGS

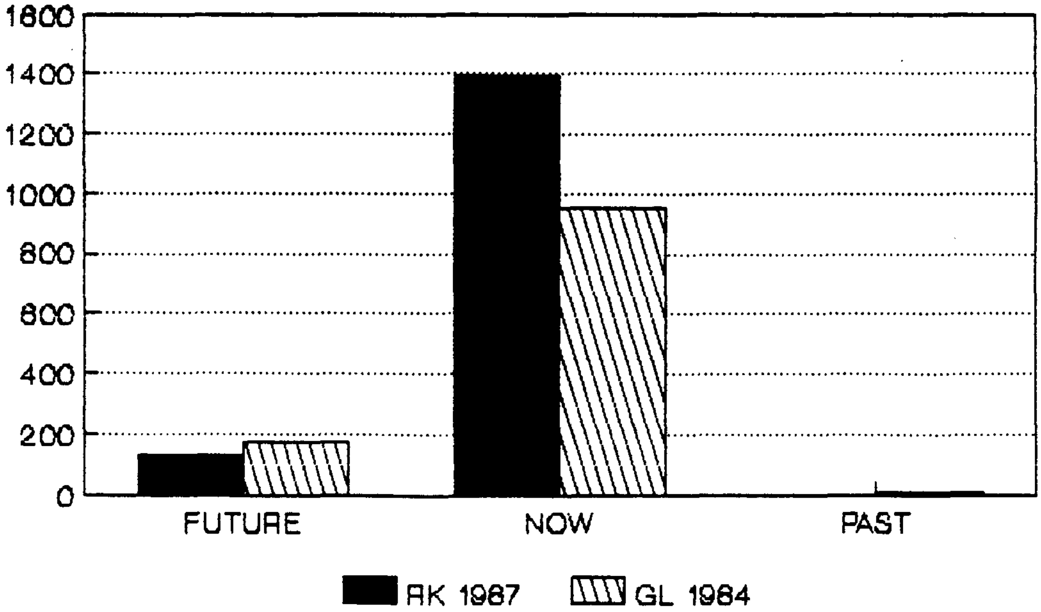


CHART 4

LOCATION
NUMBER OF MEETINGS

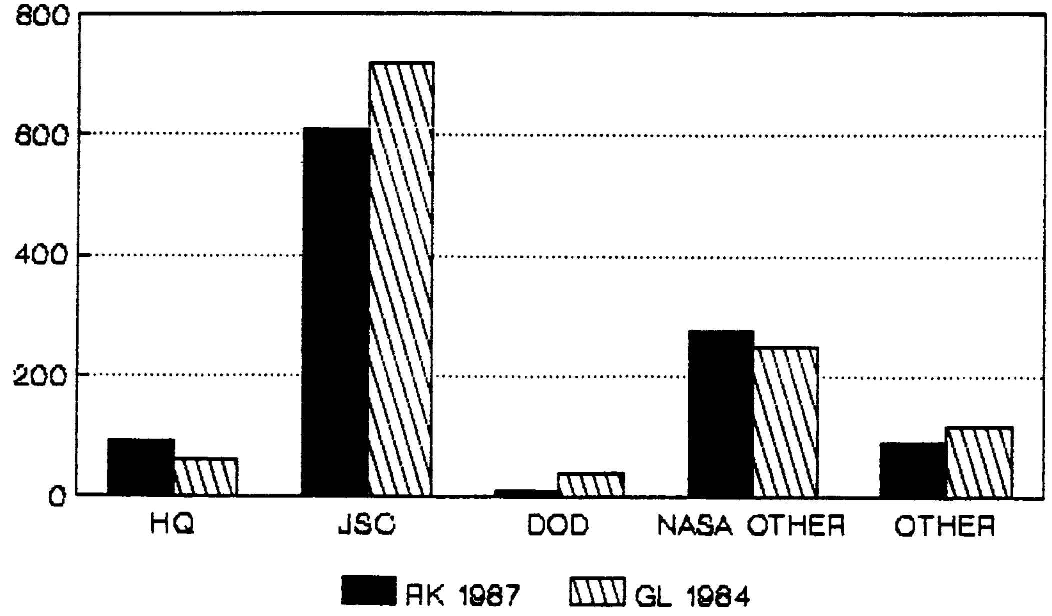


CHART 5

TIME OF MEETINGS

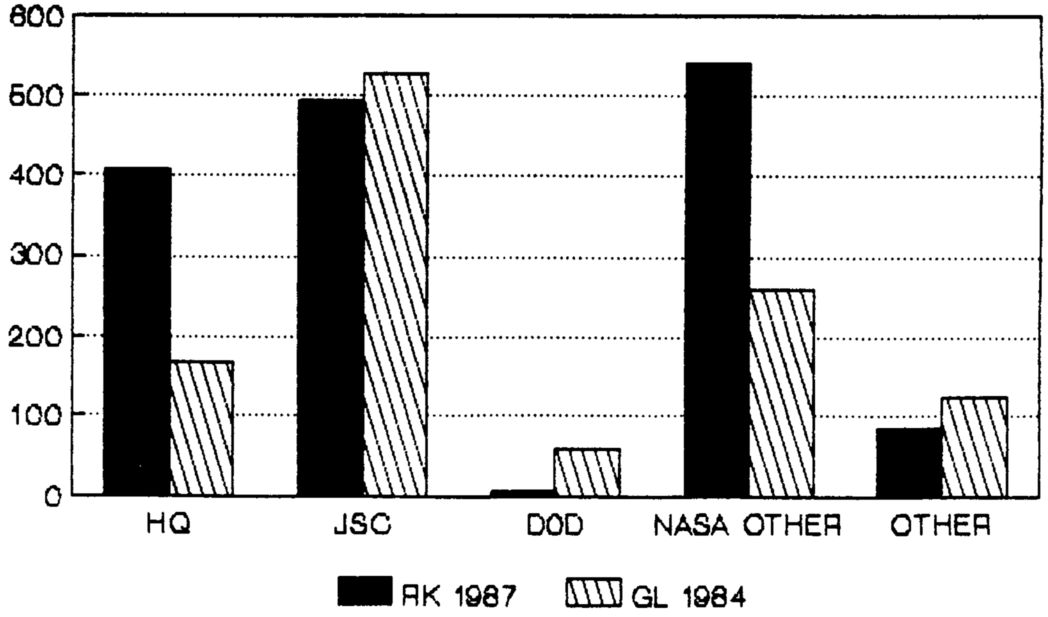


CHART 6

SUBJECT
NUMBER OF MEETINGS

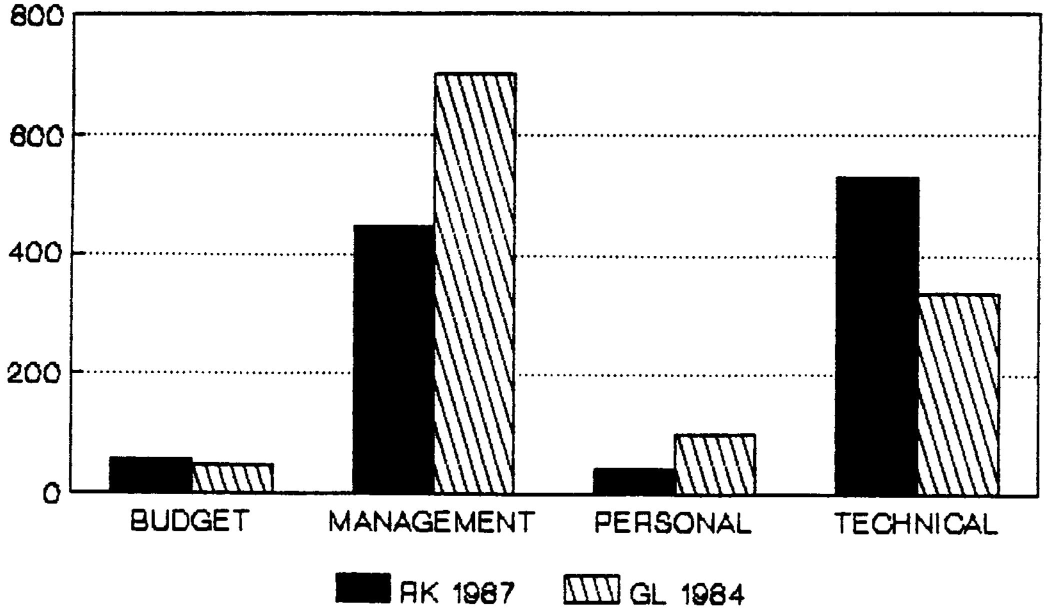


CHART 7

TIME OF MEETINGS

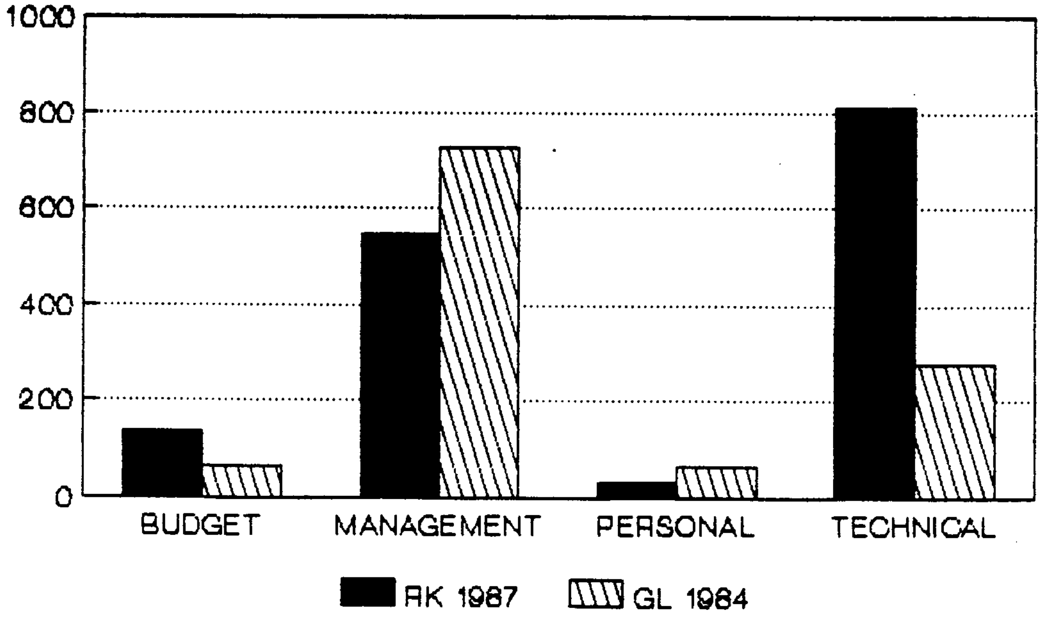


CHART 8

AGENDA SUMMARY COMPARISON CHART
RK/1987 TO GL/1984
BY MAJOR CATEGORY

	RK	GL
NUMBER OF OBSERVATIONS	1073	1184
TOTAL TIME	1524 HRS.	1134 HRS.
AVG. TIME/OBSERVATION	1.42 HRS.	0.96 HRS.

LEVEL

		NUMBER		TIME		AVG TIME
		NO.	(%)	HRS.	(%)	HRS.
ACROSS	RK	136	13	158.25	10	1.16
	GL	381	32	553.50	49	1.45
DOWN	RK	797	74	903.50	59	1.13
	GL	693	59	395.00	35	0.57
UP	RK	140	13	463.25	30	3.31
	GL	110	9	185.50	16	1.69

TIME FRAME

		NUMBER		TIME		AVG TIME
		NO.	(%)	HRS.	(%)	HRS.
FUTURE	RK	71	7	131.75	9	1.86
	GL	135	11	176.25	16	1.31
NOW	RK	1001	93	1392.75	91	1.39
	GL	1045	88	952.25	84	0.91
PAST	RK	1	<1	.50	<1	0.50
	GL	4	<1	5.50	<1	1.38

LOCATION

		NUMBER		TIME		AVG TIME
		NO.	(%)	HRS.	(%)	HRS.
DOD	RK	6	1	5.75	<1	0.96
	GL	40	3	58.00	5	1.45
HQ	RK	90	8	406.75	27	4.52
	GL	62	5	167.75	15	2.71
JSC	RK	609	57	491.00	32	0.81
	GL	717	61	523.75	46	0.73
N. OTH	RK	275	26	537.25	35	1.95
	GL	247	21	260.50	23	1.05
OTHER	RK	93	9	84.25	6	0.91
	GL	118	10	124.00	11	1.05

SUBJECT

		NUMBER		TIME		AVG TIME
		NO.	(%)	HRS.	(%)	HRS.
BUDGET	RK	57	5	136.25	9	2.39
	GL	45	4	62.75	6	1.39
MGMT.	RK	444	41	547.00	36	1.23
	GL	702	59	727.00	64	1.04
PERS.	RK	43	4	30.50	2	0.71
	GL	100	8	66.25	6	0.66
TECH.	RK	529	49	811.25	53	1.53
	GL	337	28	278.00	24	0.82

APPENDIX II D

COMPARTMENTALIZATION

INCREASING THE FLIGHT RATE
COMPARTMENTALIZATION
JLH-10 MAY 88

ASSUMPTION 1: To a large degree, the schedule is driven by the manifest, i.e., aberrations in the schedule are ofttimes caused by manifest changes.
ASSUMPTION 2: If the shuttle program is ever to be operational, in the sense that it is driven by time and cost as well as safety, then the processing procedure must be robust enough to deal with late manifest changes.
ASSUMPTION 3: A large amount of the processing is mission unique.
ASSUMPTION 4: Much of what is contained herein has already been conceptualized by others at NASA.

INTRODUCTION: In order to increase the flight rate, a means must be found of working smarter, not harder. The **only viable** way to do this is to reduce the amount of processing items which are mission unique. Training is a good example. Training now takes 11 to 12 weeks and much of it is mission unique. This 11 to 12 week period occurs immediately prior to launch. This forces the schedule to be unresponsive to any manifest change in the last 3 months of processing. There is absolutely no way the shuttle will be able to maintain a high flight rate (12 to 15 per year or more) unless the schedule is robust up to a very short time (one month ?) before launch. The only way to get robustness is to reduce variability in the sense of mission unique items. Since mission is driven by manifest, this requires that the variability in the manifest must be reduced. Note that this is different than saying that the manifest must not be changed. The schedule must be responsive to manifest changes. The implication here is that difference between payloads must be reduced. This leads to compartmentalization.

DISCUSSION: The procedure at this point is to examine all the payloads that have flown in the last several years and are likely to fly in the next several years. Parameters which determine a payload are listed with concentration on those that affect shuttle processing. This effort needs to be done with involvement from the payload community (the customers). This list then needs to be approached with the intent of placing payloads into compartments. The idea is to design processing packages of the shuttle around similar payload packages. There will be some payloads which do not fit with others. A compartment is created for them. Price incentives and early launch considerations can be used to influence the customer community to fall within one of the standard compartments as opposed to the unique compartment. Even a scientist, if he can fly cheaper or quicker, will conform to reasonable restrictions.

PROCESS: 1) Determine an OPR.
2) Decide on the amount of robustness to include in the schedule. I suggest that a target of one month be the initial value. This means that the intent should be to eventually allow manifest changes up to one month from launch.
3) A working group under the OPR with very high level influence needs to develop the payload list of parameters and determine the compartments. Five standard compartments and one unique department is a good target.
4) Once a set of compartments is determined, processing packages need to be built around all of the compartments.
5) The process needs to be reviewed periodically to insure that the packages continue to meet the needs of the customer community.
6) This activity has a long lead time. However, nothing serious is going to be done about increasing the flight rate until this activity or something similar is done. For this reason I encourage this process to be undertaken at the earliest possible date.

APPENDIX II E

STS-26 LAUNCH PREDICTIONS

LAUNCH PREDICTIONS
STS 26
JLH 11 OCT 88

INTRODUCTION:

In early July, 1987 a survey was started to predict the time of the launch of STS-26. Eight people were chosen from the Program Office of the shuttle to estimate the approximate time of the next launch. Later, for the mid-September prediction and subsequent ones, this number was expanded to include 10 people. With this exception, the same people were used for all surveys. Data was gathered on two month intervals for the middles of July 87, September 87, November 87, January 88, March 88, and May 88. The survey was halted in mid May as it was felt that the launch was close and the probabilistic nature of the survey would change.

RESULTS:

The results of this survey are shown on a bi-monthly basis in the following table and in the included charts.

Time of Prediction	Most Likely Month	50/50 Point
Mid-July 87	August	9.5
Mid-Sept. 87	August	9.8
Mid-Nov. 87	August or September	9.8
Mid-Jan. 88	August or October	9.9
Mid-March 88	August or October	9.9
Mid-May 88	October	10.0

In the table, the most likely month refers to the month chosen most often by the respondents. The 50/50 point refers to the point which represents the mean of the distribution. The mean of a distribution is, of course, the point where is a probability of 0.5 of lying to the left and a probability of 0.5 of lying to the right. The number in this column represents the month and a decimal fraction of a month. As an example, 9.9 represents the end of September.

The charts are two different representations of the bi-monthly distribution: a bar chart and a curve fitted chart. The curve fitted chart is fitted by HPG software and shows the trending of the distributions to the right, or later in the year, over the life of the survey.

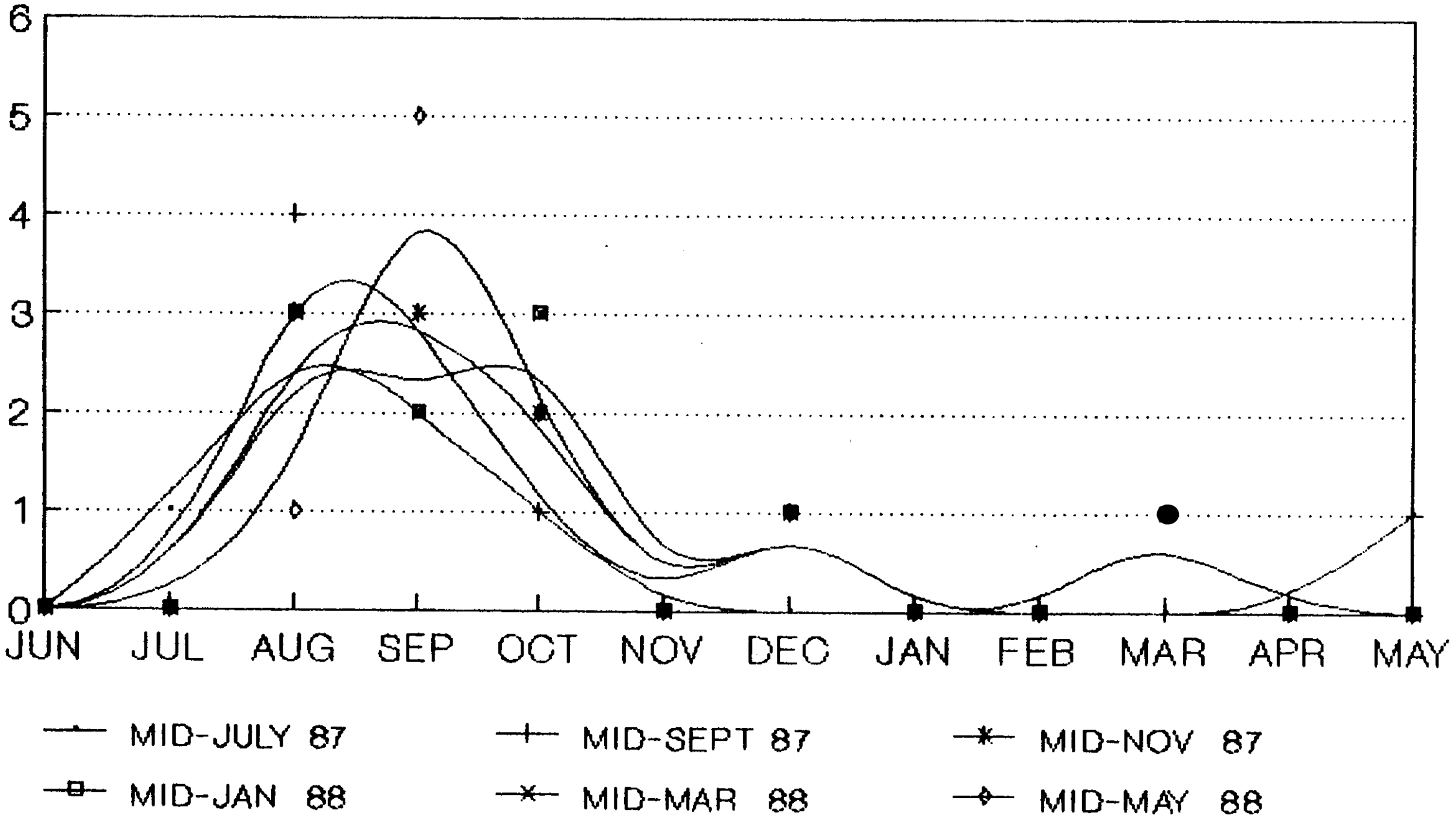
CONCLUSIONS:

As has already been mentioned, the distributions slowly moved to the right. However, at March, the group had narrowed in on late September or early October. Even though the group picked October as the most likely month for launch in their latest prediction, the survey still showed a remarkable degree of accuracy. The launch occurred on September 29, 1988 and the final mean was 10.0.

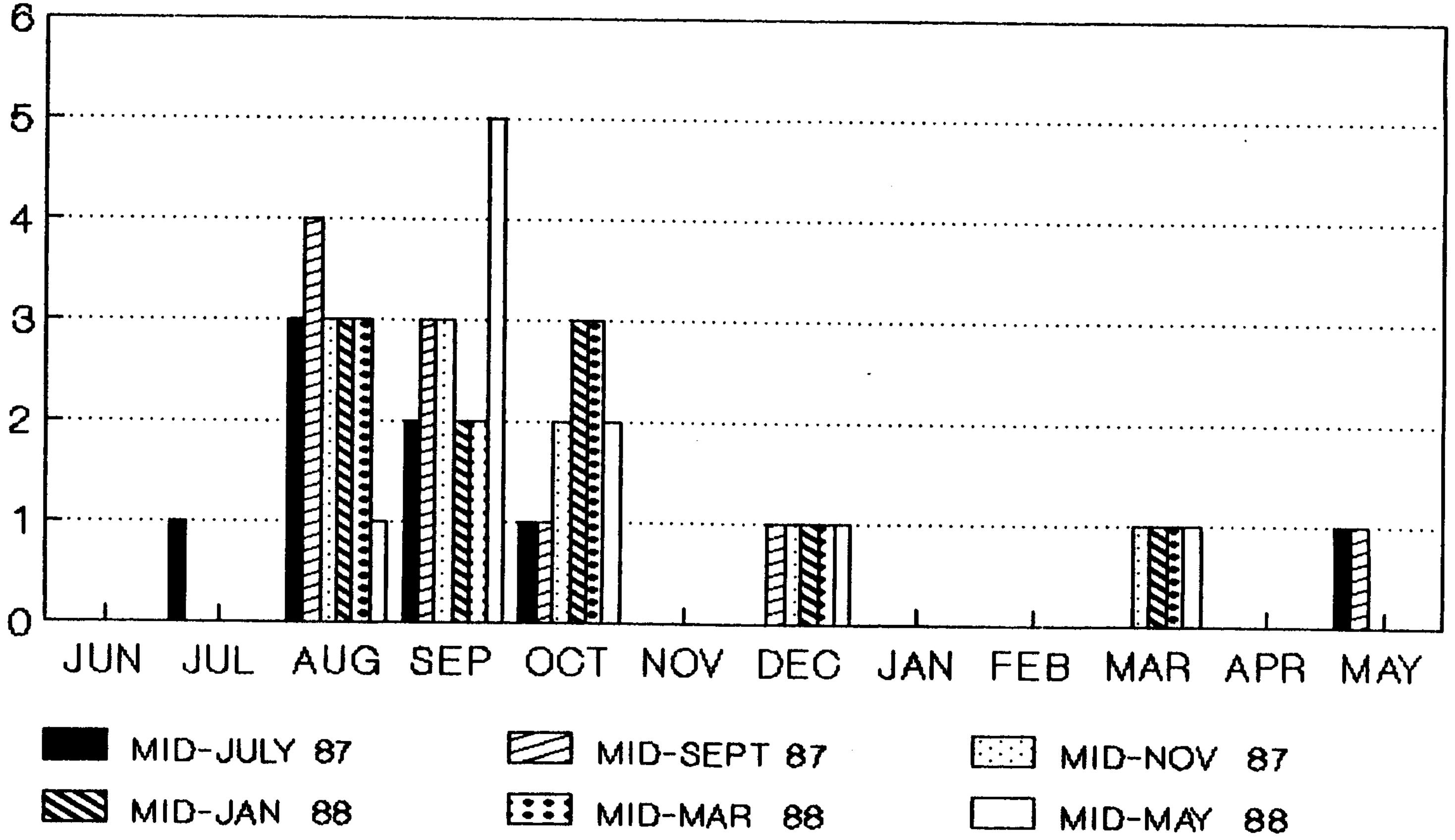
As a final comment, either this method of prediction was fairly accurate or there was a large amount of luck in the survey. Given that the survey was accurate, a reasonable conclusion is that there is a fair amount of collective knowledge in the program office which statistical methods can use to reduce uncertainty of highly probable events.

LAUNCH PREDICTIONS

STS 26



LAUNCH PREDICTIONS
STS 26



APPENDIX II F

STATISTICS FOR MANAGERIAL DECISION MAKING

DESCRIPTION
STATISTICS FOR MANAGERIAL DECISION MAKING
JLH OCT 88

In the summer of 1988, several issues arose which related to the use of statistics in decision making at upper levels in the program office. Many, if not all, of the upper level managers fall into the category of having little if any statistics in the academic backgrounds. To this end, a statistics course was developed to assist upper level managers in use of statistics in decision making. The included memo was sent from the program office to upper level management throughout the Center. The memo explains in more detail the content and objectives of the course. Also included is the teaching outline for the first two hour session.

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

AUG 0 8 1988

Reply to Attn of: NSTS-JSC, GM-88-0637

TO: Distribution

FROM: NSTS-GA/Deputy Director, National STS Program

SUBJECT: Statistics for Senior-Level Managers

Dr. J. L. Hunsucker has agreed to teach a 12-hour overview seminar in the interpretation of statistics for senior-level manager. The contents include topics from elementary probability such as event trees, marginal probability, serial events, and parallel events; basic definitions in statistics such as mean, variance, probability density functions (pdf's) and cummulative distribution functions (cdf's); specific distributions such as the normal, the Erland, and the Weilbul; sampling and hypothesis testing; and curve fitting and linear regression. These topics will build on each other. The seminar will be taught in six 2-hour sessions. The first session is scheduled for August 16, 1988, 3-5 p.m., in building 1, room 602.

The intent of the seminar is to assist managers in determining what kind of questions should be asked when statistical information is presented and to assist them in the interpretation of statistical results. In the presentation of the material of the seminar, it will be assumed that the managers attending come from technical backgrounds, have had some experience with seeing reports with statistical information, and have forgotten most, but not all, of the formal mathematics they had while obtaining their degrees.

For further information, please call Dr. Hunsucker at JSC extension 31353 or FTS 525-1353.

f Jay F Honeycutt

Richard H. Kohrs

PROBABILITY AND STATISTICS FOR MANAGERIAL DECISION MAKING

J. L. HUNSUCKER
DEPT. OF INDUSTRIAL ENGINEERING
UNIVERSITY OF HOUSTON

SECTION 1: PROBABILITY

1. DEFINITION: A function P defined on a set S is said to be a probability function on S provided

   a) 0 <= P(A) for A any subset of S
   b) P(S) = 1
   c) P(A UNION B) = P(A) + P(B) if A INTERSECT B is empty.

2. NOTE: An applied definition of probability is

$$\frac{\text{number of successful events}}{\text{total number of events}}$$

Regardless of which definition is used, probability refers to long term frequency.

3. EXAMPLE: Consider 3 quarters tossed on a table top. The following table shows the possible outcomes.

	Q	
H	H	H
H	H	T
H	T	H
H	T	T
T	H	H
T	H	T
T	T	H
T	T	T

Since there are two choices for each quarter and three quarters there are

2**3 = 8

possible outcomes. The probability of getting HHH is 1/8. As an aside, the set S consists of these 8 outcomes. There are 2**8 different subsets of S. Let A be one of these subsets. If we define P(A) as the number of elements in A divided by the number in S then we have a function which satisfies the formal definition above.

4. DEFINITION: N(A) is the number of elements in a set A.

5. EXAMPLE (CONTINUED): Let A be the event, in the example in 3, that at least two heads are obtained. Then

P(A) = N { HHH, HHT, HTH, THH } / 8 = 4/8 = 0.5

6. NOTE: The probability of obtaining a head with 1 coin is 0.5. Suppose your first flip is a tail. What about the next flip?

7. NOTE: ODDS - If the odds are 3:2 on an event then the probability of the event is

$$\frac{3}{3 + 2} = 3/5 \text{ or } 0.6$$

8. NOTE: a) If A is an event and ~A means not A then
P(~A) = 1 - P(A)
b) If A and B are events then
P(A union B) = P(A)+P(B)-P(A intersect B)

9. NOTATION: P(A\B) means the probability of that A will occur given that B will occur.

10. P(A\B) = P(A INTERSECT B)/ P(B) since B becomes the universe.

11. EXAMPLE: Suppose in a given sample of 400 we have:

150 redheads
100 blue eyed
50 one or more gold teeth

50 blue eyed red heads
30 blue eyed with gold teeth
25 redheads with gold teeth
10 with all three.

If your escort for the evening is to be drawn from this sample find the probability that:

a) you get a blue eyed redhead with gold teeth
b) you get a red head
c) given that you get a redhead, the probability of gold
d) given that you get a gold toothed redhead, the probability of blue eyes.

a) P(BE&RH&GT) = 10/400 = 0.025

b) P(RH) = 150/400 = 0.375

c) P(GT\RH) = N(GT&RH)/N(RH) = 25/150 = 0.17

d) P(BE\GT&RH) = N(BE&GT&RH)/N(GT&RH) = 10/25 = 0.60

12. DEFINITION: If A and B are two events then they are said to be independent if and only if

P(A\B) = P(A) or equivalently P(B\A) = P(B)

13. NOTE: If A and B are independent then

P(A intersect B) = P(A) * P(B)

14. EVENT TREES: Sometimes it is possible to construct an event tree with associated probabilities.

15. EXAMPLE: There are two sub-assemblies, A and B which comprise an electronics unit. If the device fails, the probability that A must be replaced is 0.50. Sometimes A failing damages B. If A must be replaced, the probability that B must be replaced is 0.70. If A does not need replacing, the probability that B must be replaced is 0.10. What is the probability that both A and B must be replaced? Given that B must be replaced, what is the probability that A must be replaced?

```
             B REP     0.5 * 0.7 = 0.35
            /
           /0.7
    A REP /
   /      \ 0.3
  /0.5     \
 /          \
/            B ~REP    0.5 * 0.3 = 0.15
\
 \ 0.5         B REP   0.5 * 0.1 = 0.05
  \          /
   \        /0.1
    A ~REP /
           \ 0.9
            \
             \
              B~ REP   0.5 * 0.9 = 0.45
```

P(A&B) = 0.35   P(A\B) = 0.35/(0.35 + 0.05) = 7/8 = 0.875

16. RELIABILITY - PARALLEL AND SERIAL

A)   PARALLEL:

```
       ---A---
      ¦       ¦
      ¦       ¦
------¦       ¦----->
      ¦       ¦
      ¦       ¦
       ---B---
```

This system works if either A or B works. So the P(success) = P(A or B).

B) TWO DIFFERENT METHODS:

1)   P(A OR B) = P(A) + P(B) - P(A&B)

This method works well for two elements. The formula is much more complicated for more elements.

2)   P(success) = 1 - P(failure) = 1 - P(~A) * P(~B)

This method works regardless of the number of elements.

C) EXAMPLE: Two elements in parallel with P(A) = 0.7 and P(B) = 0.6. What is the probability of success?

Method 1: P(success) = 0.7 + 0.6 - 0.7 * 0.6 = 0.88

Method 2: P(failure) = P(~A) * P(~B) = (1-0.7)*(1-0.6)
= 0.3 * 0.4 = 0.12
P(success) = 1 - 0.12 = 0.88

D) EXAMPLE: We would like to have a 0.95 confidence in a system working. The major component of the system has a 0.6 reliability but can be placed in parallel. How many parallel components do we need?

1 - (0.4)**n = 0.95

0.05 = (0.4)**n   n = ln (0.05)/ln (0.4) = 3.269 or
4 units required.

E) SERIAL: Serial probabilities multiply.

Suppose you have 4 components in line A--B--C--D with probabilities of 0.90, 0.95, 0.92, and 0.96. Then

P(success) = .90 * 0.95 * 0.92 * 0.96 = 0.76

17. EXPECTATION AND DECISION MAKING

If the probabilities of obtaining amounts a1, ... , an are given by p1, ... , pn then the expectation is given by

a1*p1 + a2*p2 + ... + an*pn

18. NOTE: 1) In order to use expectation, a1,...,an must represent all outcomes.
2) In practical applications, it is often difficult to determine p1,...,pn.
3) Expectation is what is to be expected over a large number of trials.

19. EXAMPLE: It costs $60 to test a component and $1200 to replace and repair the damage if it fails. If it is known that 3% of all components are defective, should you test them?

EXP(no test) = 0.03*1200 + 0.97*0 = $36

So testing is not cost effective.

20. EXAMPLE: The following table gives the probabilities for various life expectancies of two different types of power plants. Which type will cost less per year of useful life?

yrs	10	20	30	40	CONST COST/KWH
LWR	0.05	0.25	0.50	0.20	300
FF	0.10	0.50	0.30	0.10	150

EXP LIFE (LWR) = 10*0.05 + 20*0.25 + 30*0.50 + 40*0.20 = 28.5

EXP LIFE (FF) = 10*0.10 + 20*0.50 + 30*0.30 + 40*0.10 = 24

```
                  LWH                        FF
EXP COST/KWH
------------ = 300/28.5 = $10.53          150/24 = $6.25
YEAR
```

Suppose the construction of the LWR has a 50-50 chance of increasing by $50/KWH. What impact does this have on the LWR cost?

EXP COST = 10.53 * 0.5 + 350 * 0.5 = $11.41

CHAPTER III

HEURISTIC PROGRAMMING STUDY OF A FLOW SHOP WITH MULTIPLE PROCESSORS

III. HEURISTIC PROGRAMMING STUDY OF A FLOW SHOP WITH MULTIPLE PROCESSORS

1.0 INTRODUCTION

Scheduling procedures are generally classified as either localized or centralized. The advantage of local rules is in that they are based upon the most up to date information on the state of the machine or work center. Queuing or dispatch rules are examples of such scheduling procedures. The advantage of centralized rules is that they consider a larger picture. Mathematical and heuristic algorithms, such as Johnson's algorithm for the two machine flow shop (Baker 1974) or the Smith Panwalker and Dudek heuristic algorithm for the general flow shop (Smith et al. 1975) are examples of centralized rules. The drawback of overlooking the global picture in localized rules is overcome by using centrally drawn schedules. However, the price of centralization is paid in the form of computation or response time, which in turn predicates the reaction to changes in the system.

Due to the limitation of computation time for even a problem of modest size, localized rules sometimes provide the only way of finding a feasible solution to the problem. Furthermore, the use of heuristic programming investigation through the method of computer simulation for localized scheduling using dispatch or queueing rules furnishes an alternate to the algebraic or probabilistic methods. The effect of dispatching procedures in simulation models is very difficult to describe, nevertheless, the study of such heuristic rules contributes to a valuable understanding of the system for different measures of performance.

The purpose of this heuristic programming study is to investigate the behavior of two regular measures of performance, mean flow time and makespan, in a FSMP. The scheduling or dispatch rules used in the study are localized rules. However, the priorities for scheduling the jobs, in the simulation model, are established dynamically at each stage of processing.

2.0 SIMULATION MODELING

Computer simulation involves experimentation on a computer based model of some system. The simulation model in such an evaluation, often seeks to duplicate the behavior of the system in order to demonstrate the likely effect of various policies. One of the main strengths of this approach is that it abstracts the essence of the problem and reveals its underlying structure. This provides insight into cause-and-effect relationships within the system. If it is possible to construct the mathematical model which is both a reasonable representation of the actual situation and solvable in a manageable amount of time, then the analytical technique is of course superior to simulation. However, the large scale FSMP scheduling problems are so complex that to carry out fully integrated analyses, the analytical techniques cannot be usefully utilized. In such situations, even though it may still be relatively complicated to perform computer simulation, often it may be the only practical approach to the problem.

The first step in the heuristic programming study of the simulation model of the FSMP scheduling problem is to build a model. The model under study is that of a static FSMP for which all jobs are simulated to arrive at the beginning of each simulation run. The processing times of the jobs are generated from a uniform distribution between 0 and 100. Further, all jobs are assumed to be available at the beginning of simulation, i.e., the arrival time of all jobs is zero. The system works on nondelay schedules with no preemption allowed. Whenever a waiting line develops in front of a processing stage, a dynamic queuing discipline is used to set the priority. The job with the highest priority in the queue is scheduled next whenever a processor becomes available. The analysis for each set of processing data is repeated for all priority rules and the measures of performance are recorded and contrasted. Although in real life it is possible to have an unequal number of parallel processors at each stage, nevertheless, in order to limit the study, only an equal number of parallel processors is investigated in this research. The flow diagram of the simulation model of a FSMP is presented in Figure 3.1.

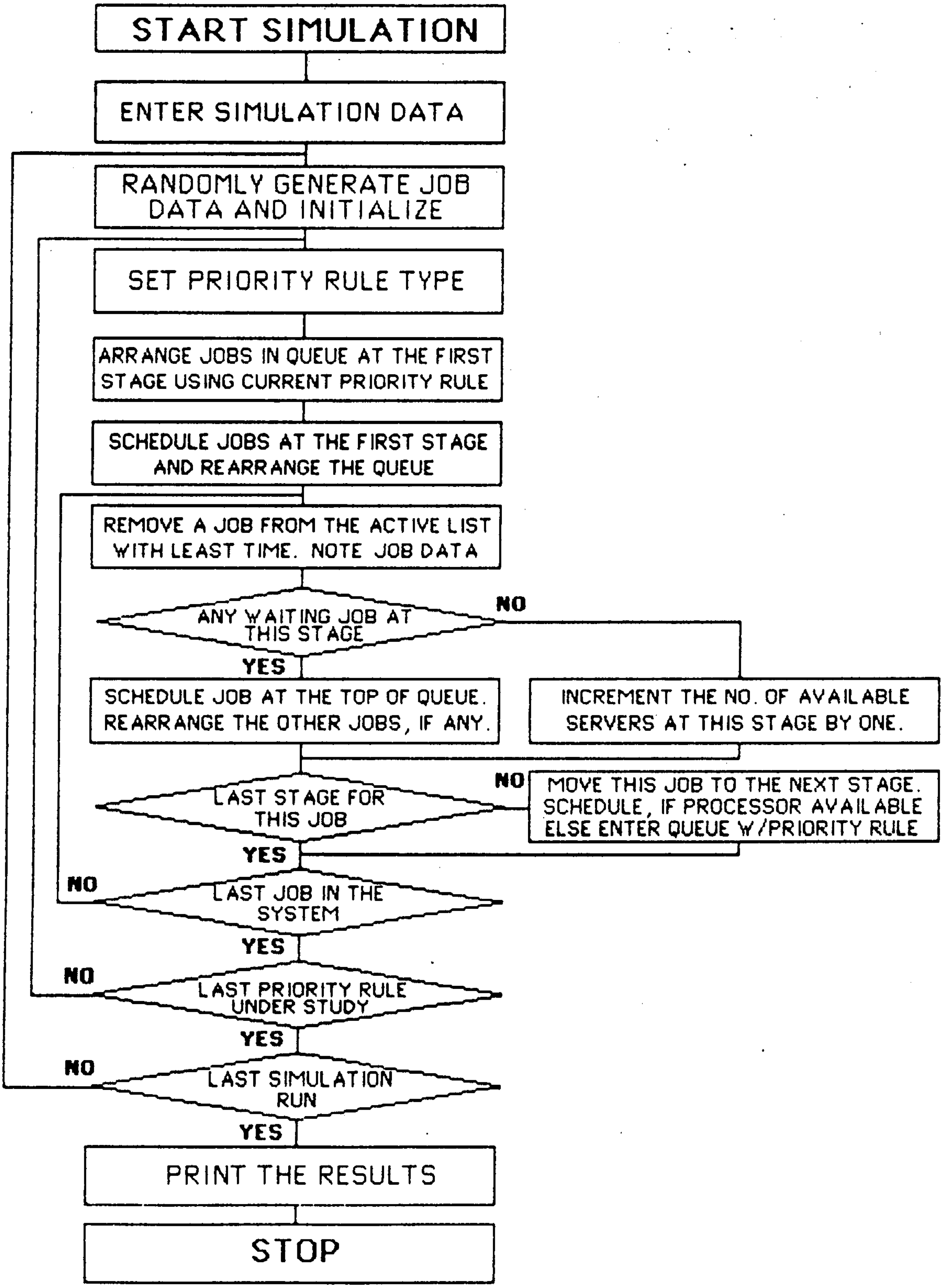


FIGURE 3.1. THE FLOW DIAGRAM OF THE SIMULATION OF A FSMP PROBLEM.

The model is run for one hundred data sets for various number of jobs and processing stages, and a given number of parallel processors at each stage. For each simulation data set, the performance of priority rules is measured for two measures of performance, namely the mean flow time and the makespan. The best rule for the data set under consideration is selected for each criteria and the performance score of the priority rule responsible for obtaining the best solution of each performance measure is increment by one. In case of ties, the scores of all priority rules in the tie are increment. Naturally this would imply that the sum of the scores on all priority rules could be greater than one hundred. Also, the mean flow time and the makespan are recorded for the priority rules and the averages over one hundred simulation runs are reported.

Many simulation studies have been performed mostly for the job shop cases, see the RAND studies (Convey et al. 1967), Baker (1974), Panwalker and Iskander (1977), Buzacott and Shanthikumar (1985), O'Grady and Harrison (1985), Scudder and Hoffmann (1985), Kim (1987), Russell et al. (1987), Vepsalainen and Morton (1987), and Yao and Kim (1987). In studies involving makespan and mean flow time criteria, the local scheduling rules mentioned below are the most commonly studied. The list of rules studied here is certainly not exhaustive. Also, there are other priority rules which are not applicable to the FSMP problem. The priority or heuristic rules considered for the simulation study of the FSMP scheduling problem are listed below:

- FIFO (First In First out): Select the operation of the job which was first to enter the queue at that stage.
- LIFO (Last In First Out): Select the operation of the job which last entered the queue for service.
- SPT (Shortest Processing Time First): Select the operation with the minimum processing time.
- LPT (Largest Processing Time First): Select the operation with the largest processing time.
- MTWF (Most Total Work First): Select the operation with the maximum total work in the flow shop.
- LTWF (Least Total Work First): Select the operation with the minimum total work in the flow shop.
- MWRF (Most Work Remaining First): Select the operation associated with the job having the most work remaining.
- LWRF (Least Work Remaining First): Select the operation associated with the job having least work remaining.
- RANDOM (Random): Select the operation at random.

3.0 PRESENTATION OF FINDINGS

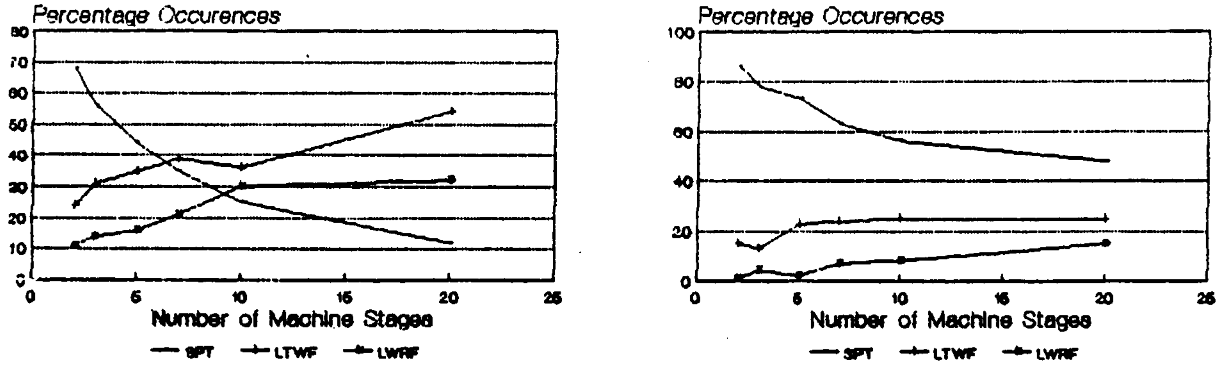
As discussed before, the mean flow time and the makespan criteria for a FSMP, were studied for the number of occurrences of the best solution among the rules considered and the average value of the parameters over the simulation runs. The number of times the best solution was achieved is considered as an indicator of the performance of the rule, while the average value of the measures represent the overall performance.

Six sets of jobs, and six sets of machine stages for each job set, were studied for 1-5, 7 and 10 parallel processors at each stage of processing for all of the priority rules.

3.1 MEAN FLOW TIME CRITERIA

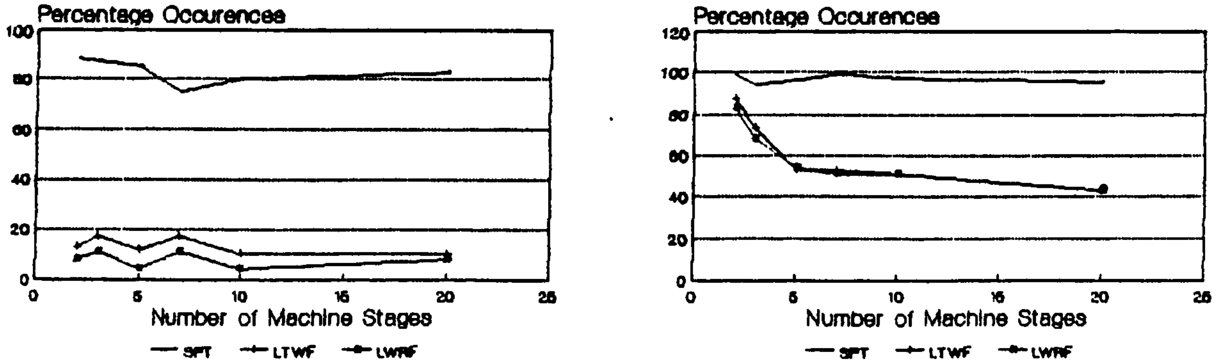
Figures 3.2 through 3.7 exhibit the performance in terms of the number of occurrences of the three most significant priority rules considered, namely the SPT, LTWF and LWRF, for the mean flow time criteria. The number of jobs, the number of machine stages and the number of parallel processors at each stage are the three variables studied in these figures. For each figure one of these variables is kept constant, while the other is varied for each one of the four graphs. The third variable is studied as an independent variable for the dependent variable of the number of occurrences of the priority rules under study in each graph.

Figure 3.2 shows the performance of the three rules in terms of the number of occurrences with respect to the number of machine stages, for a fixed number of jobs and



n=10; # of Processors at each stage = 1.

n=10; # of Processors at each stage = 3.



n=10; # of Processors at each stage = 5.

n=10; # of Processors at each stage = 7.

FIGURE 3.2. MEAN FLOW TIME RESULTS OF SIMULATION STUDY.

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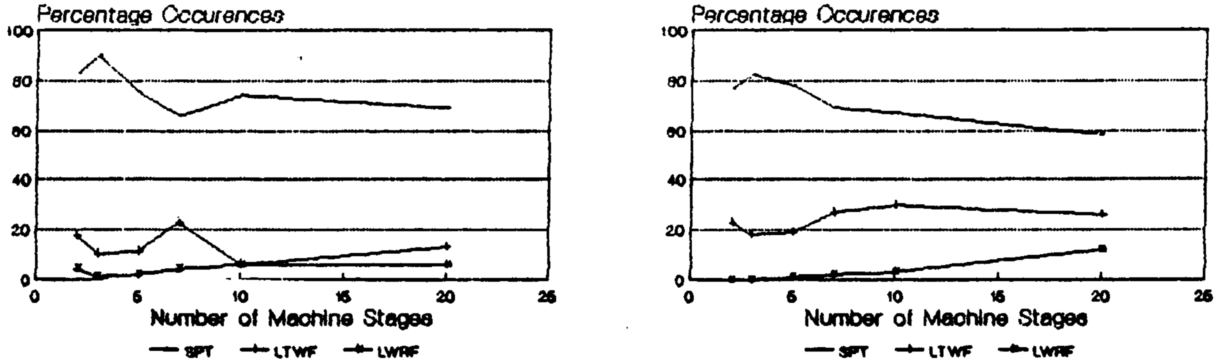
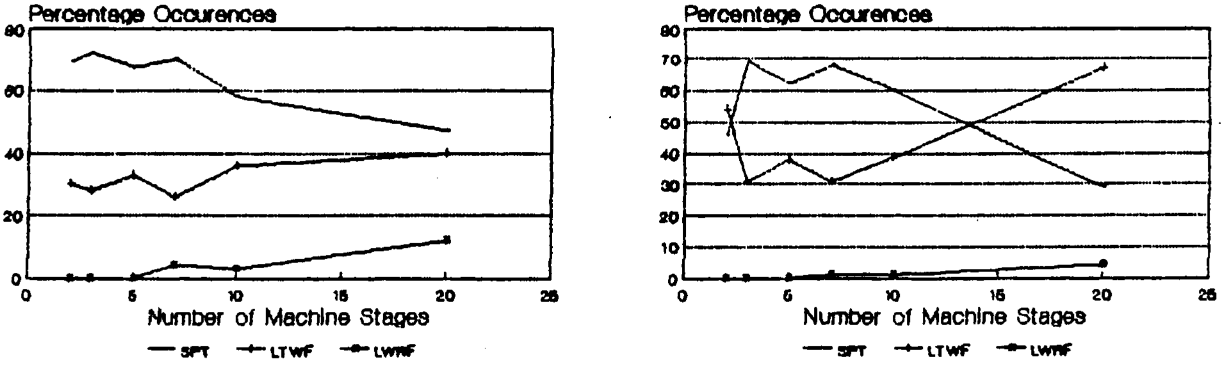


n=10; # of Processors at each stage = 4.

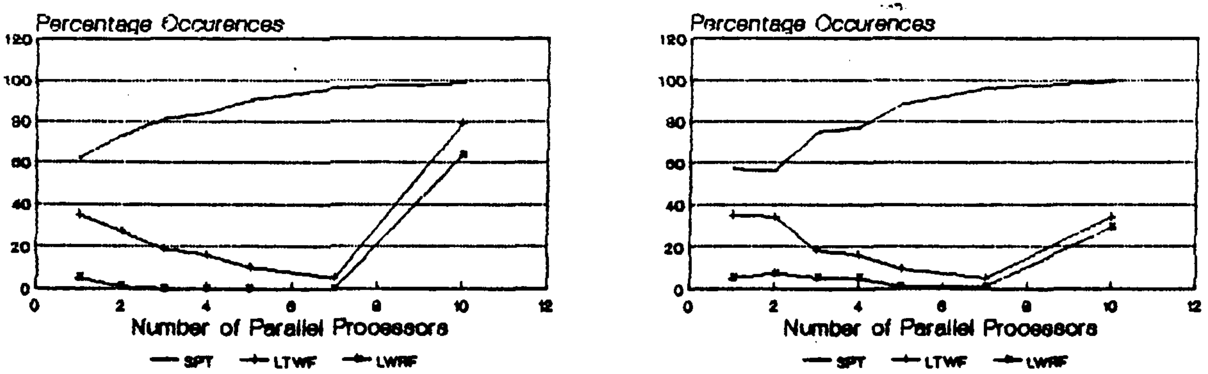
n=20; # of Processors at each stage = 4.



n=30; # of Processors at each stage = 4.

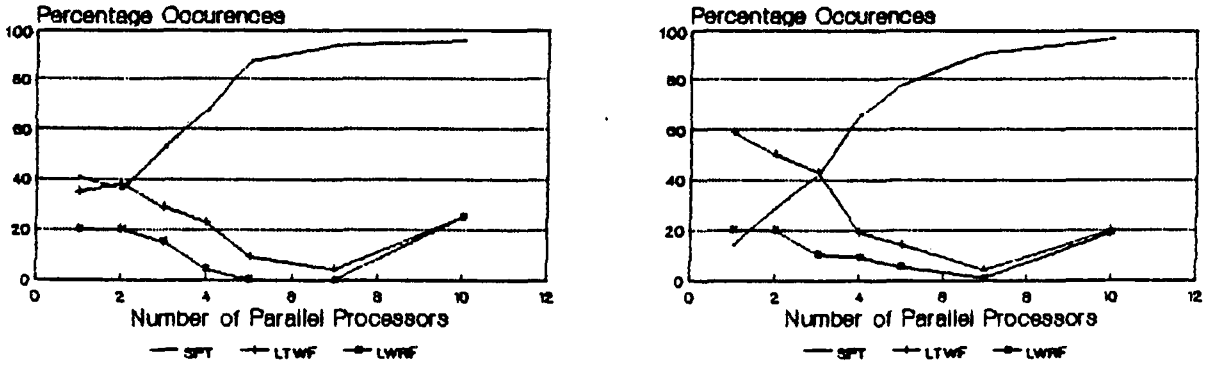
n=50; # of Processors at each stage = 4.

FIGURE 3.3. MEAN FLOW TIME RESULTS OF SIMULATION STUDY.



n=15; m=2.

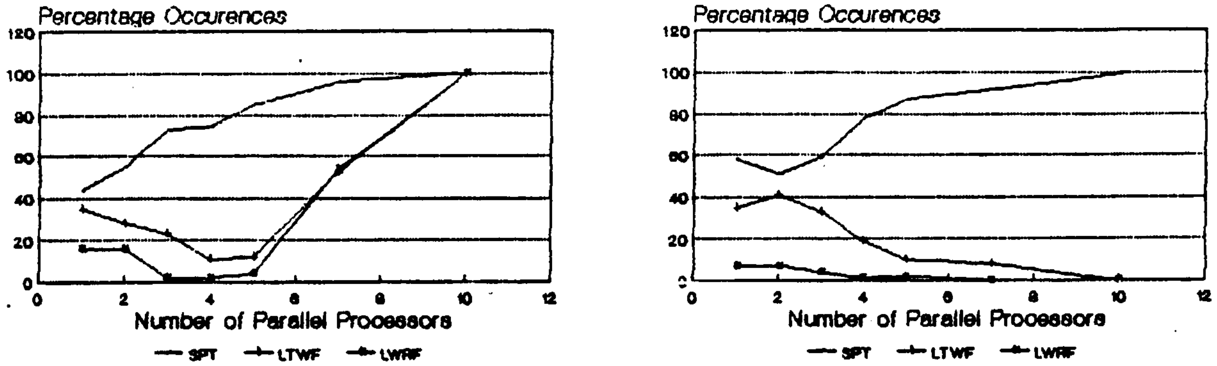
n=15; m=5.



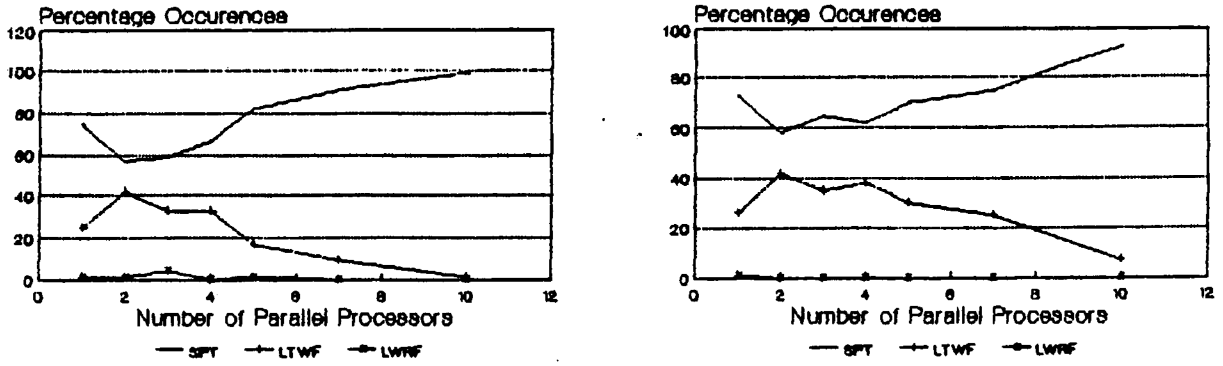
n=15; m=10.

n=15; m=20.

FIGURE 3.4. MEAN FLOW TIME RESULTS OF SIMULATION STUDY.

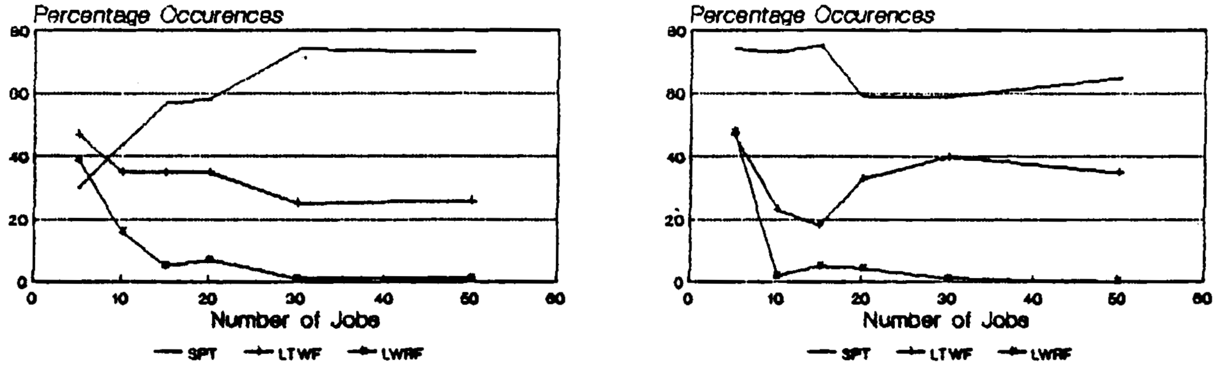


n=10; m=5. n=20; m=5.



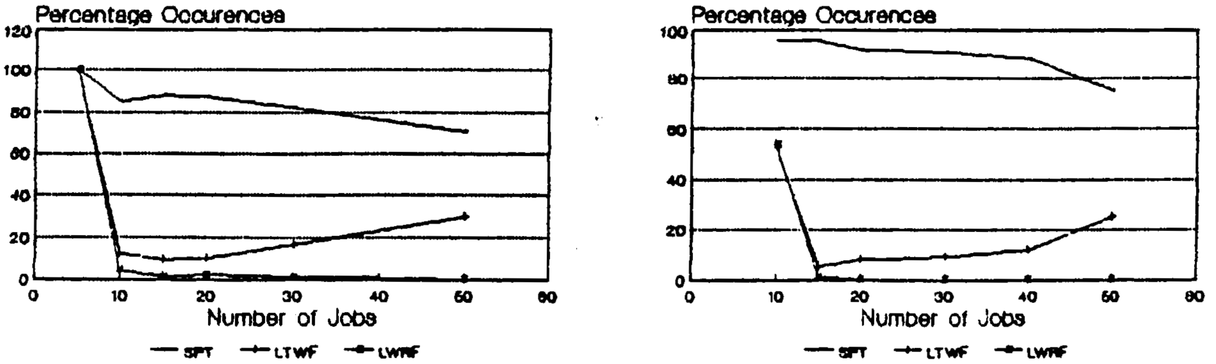
n=30; m=5. n=50; m=5.

FIGURE 3.5. MEAN FLOW TIME RESULTS OF SIMULATION STUDY.



m=5; # of Processors at each stage = 1.

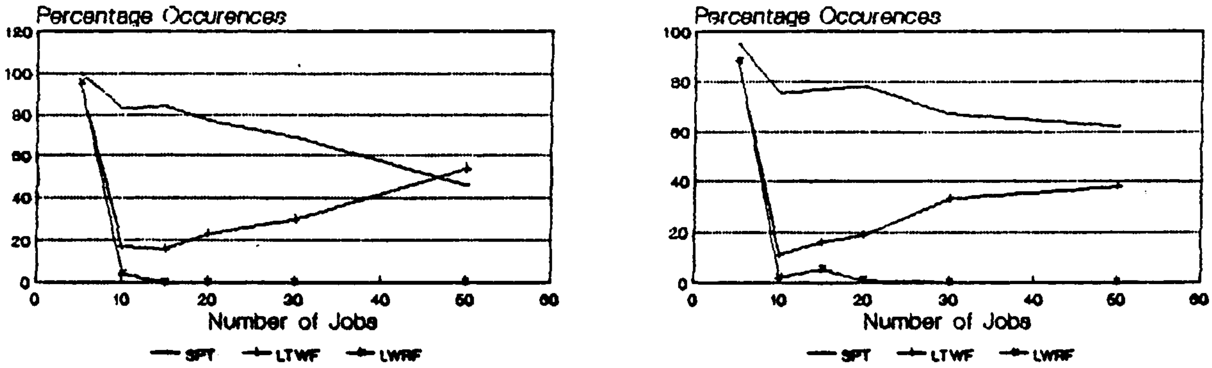
m=5; # of Processors at each stage = 3.



m=5; # of Processors at each stage = 5.

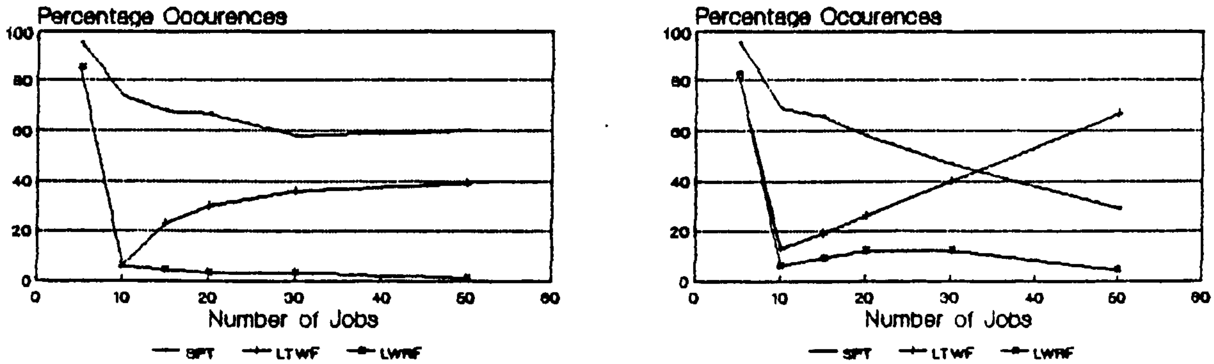
m=5; # of Processors at each stage = 7.

FIGURE 3.6. MEAN FLOW TIME RESULTS OF SIMULATION STUDY.



m=2; # of Processors at each stage = 4.

m=5; # of Processors at each stage = 4.



m=10; # of Processors at each stage = 4

m=20; # of Processors at each stage = 4

FIGURE 3.7. MEAN FLOW TIME RESULTS OF SIMULATION STUDY.

parallel processors. The four graphs of the figure are for ten jobs, and 1, 3, 5 and 7 parallel processors, respectively, at each stage of processing. Figure 3.3 is similar to Figure 3.2, except that the number of parallel processors is a constant with a value of four, and the graphs are for 10, 20, 30 and 50 jobs, respectively, as the other constant for each graph. Similarly, Figures 3.4 and 3.5 show the performance of the three rules in terms of the number of occurrences with respect to the number of parallel processors for a fixed number of jobs and machine stages. The four graphs of the Figure 3.4 are for fifteen jobs, and 2, 5, 10 and 20 machine stages, respectively. In Figure 3.5, the performance of 10, 20, 30 and 50 jobs, respectively, is observed against the number of parallel processors for five machine stages case. Finally, Figures 3.6 and 3.7 show the performance of the same three rules in terms of the number of occurrences, with respect to the number of jobs for a given number of parallel processors and machine stages. The four graphs of the Figure 3.6 are observed for the changes in the performance of rules with respect to the number of jobs for five machine stages, and 1, 3, 5 and 7 parallel processors, respectively. While, the graphs of Figure 3.7 are observed for the number of jobs as a variable for 2, 5, 10 and 20 machine stages, respectively, and four parallel processors at each stage.

Further, Table 3.1 shows the percentage decrease in the mean flow time, or the relative superiority in the

TABLE 3.1. PERCENTAGE DECREASE IN THE MEAN FLOW TIME OF THE SPT RULE w.r.t. THE RANDOM RULE.

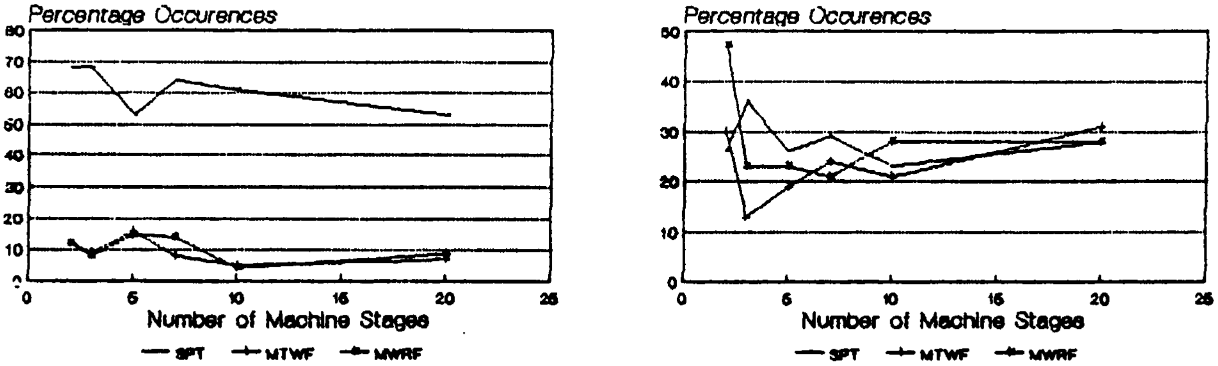
n x m	NUMBER OF PARALLEL PROCESSORS				
	1	2	3	4	5
5 x 2	20.5	11.2	4.35	0.78	0
5 x 3	18.0	9.94	3.00	0.45	0
5 x 5	12.3	5.96	2.20	0.31	0
5 x 7	8.58	4.33	1.34	0.19	0
5 x 10	5.37	3.63	1.49	0.17	0
5 x 20	3.93	1.71	0.71	0.07	0
10 x 2	27.1	20.3	16.1	11.3	7.76
10 x 3	20.8	17.3	13.6	8.95	5.59
10 x 5	14.6	13.4	8.44	5.19	3.04
10 x 7	12.6	10.3	7.14	4.45	2.43
10 x 10	7.90	5.21	4.77	3.00	1.58
10 x 20	4.65	4.41	2.51	1.55	0.80
15 x 2	27.6	22.9	21.3	18.4	14.5
15 x 3	23.4	21.4	16.9	12.8	11.0
15 x 5	16.9	14.2	11.7	8.87	7.18
15 x 7	14.2	10.0	8.70	7.32	6.17
15 x 10	9.93	8.17	6.89	5.34	3.73
15 x 20	4.69	5.04	4.48	2.79	1.98
20 x 2	28.6	26.8	22.6	21.1	17.4
20 x 3	22.3	22.0	19.2	16.5	13.6
20 x 5	16.4	15.2	13.6	10.9	9.55
20 x 7	15.1	13.1	10.3	9.10	7.08
20 x 10	11.1	10.5	8.53	6.52	5.59
20 x 20	5.80	5.38	4.74	3.59	2.83
30 x 2	27.9	26.1	24.8	24.7	21.6
30 x 3	24.0	21.9	21.3	19.4	17.6
30 x 5	18.8	16.7	15.4	14.2	12.9
30 x 7	15.4	13.7	12.3	11.1	10.1
30 x 10	11.9	10.4	9.74	8.38	7.82
30 x 20	7.36	5.79	5.84	5.10	4.02
50 x 2	27.5	26.9	26.7	24.4	25.2
50 x 3	21.4	21.2	21.2	20.5	19.9
50 x 5	17.9	16.9	16.8	15.8	15.4
50 x 7	15.1	14.5	13.2	13.4	12.4
50 x 10	12.7	11.9	10.4	10.2	9.83
50 x 20	7.97	7.17	6.25	5.51	6.22

performance of the SPT as compared to the RANDOM priority rule for the mean flow time criteria.

3.2 MAKESPAN CRITERIA

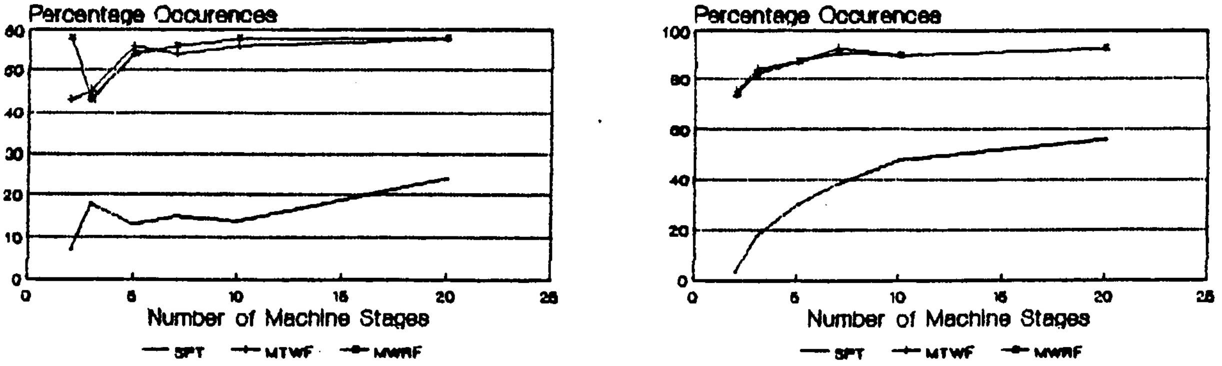
Some of the results of the simulation study for the makespan criteria are exhibited in Figures 3.8 through 3.10. The performance in terms of the number of occurrences of the three most significant priority rules, namely SPT, MTWF and MWRF, for the makespan criteria is presented graphically in these figures. The method of presentation of the graphs is similar to the one adopted for the mean flow time criteria.

Figure 3.8 shows the performance of the three rules in terms of the number of occurrences, with respect to the number of machine stages for a fixed number of jobs and parallel processors. The four graphs of the figure are for ten jobs, and 1, 3, 5 and 7 parallel processors, respectively, at each stage of processing. Similarly, Figure 3.9 shows the performance of the three rules in terms of the number of occurrences with respect to the number of parallel processors for a given number of jobs and machine stages. The four graphs of the figure are examined for 10, 20, 30 and 50 jobs, respectively, and five machine stages. Finally, Figure 3.10 shows the performance of the same three rules in terms of the number of occurrences with respect to the number of jobs for a given number of parallel processors and machine stages. The observed graphs in this case are



n=10; # of Processors at each stage = 1.

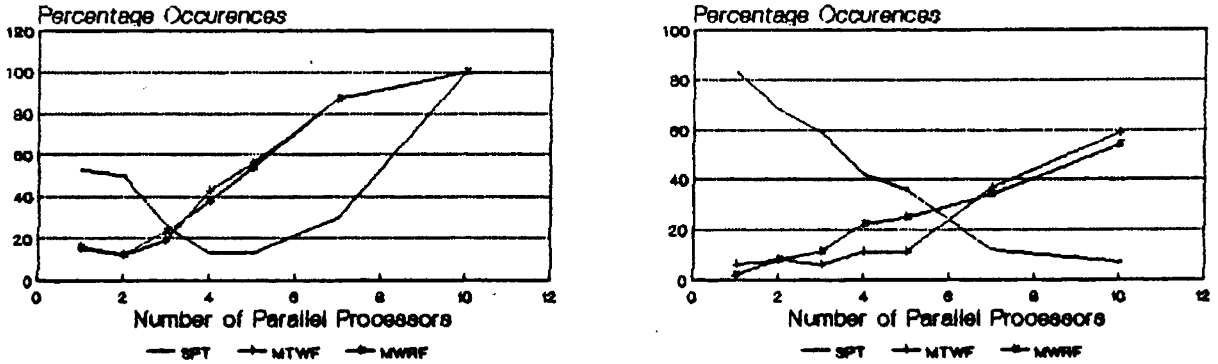
n=10; # of Processors at each stage = 3.



n=10; # of Processors at each stage = 5.

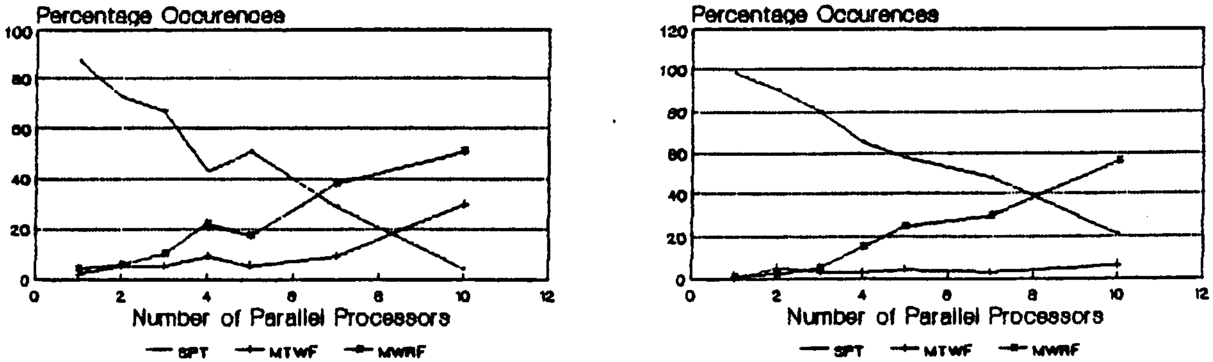
n=10; # of Processors at each stage = 7.

FIGURE 3.8. MAKESPAN RESULTS OF SIMULATION STUDY.



n=10; m=5.

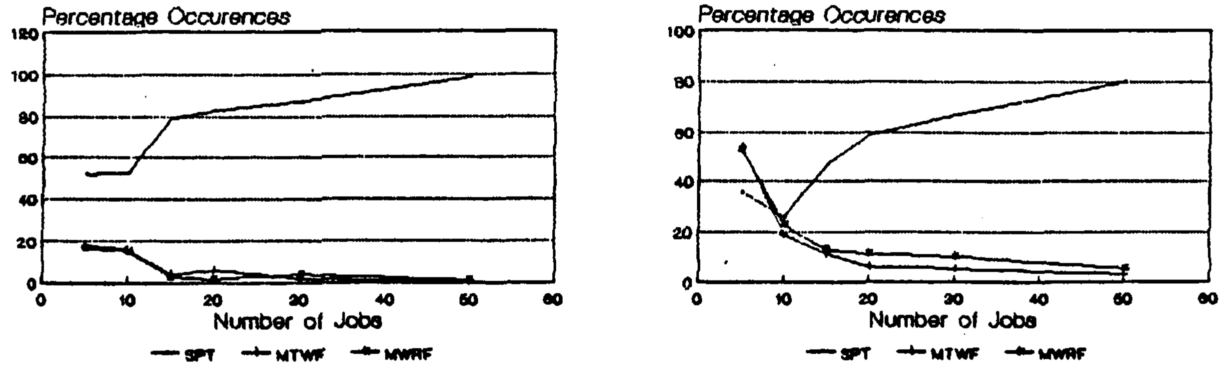
n=20; m=5.



n=30; m=5.

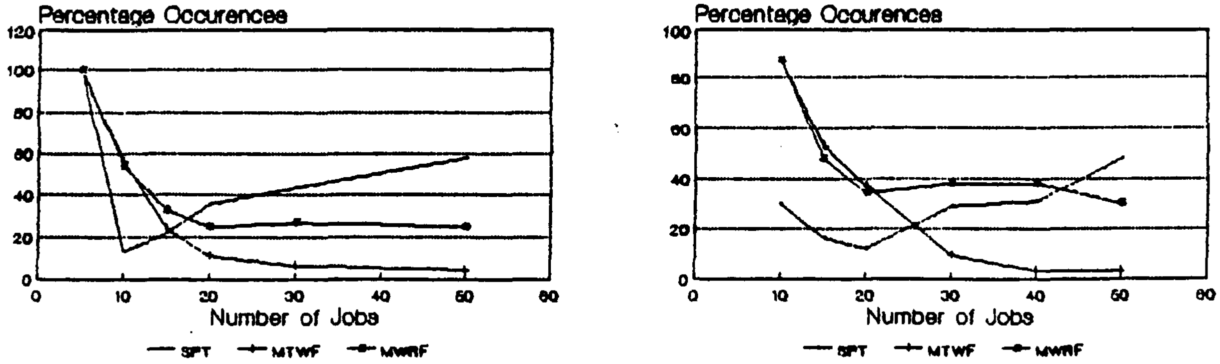
n=50; m=5.

FIGURE 3.9. MAKESPAN RESULTS OF SIMULATION STUDY.



m=6; # of Processors at each stage = 1.

m=6; # of Processors at each stage = 3.



m=6; # of Processors at each stage = 5.

m=6; # of Processors at each stage = 7.

FIGURE 3.10. MAKESPAN RESULTS OF SIMULATION STUDY.

for five machine stages, and 1, 3, 5 and 7 parallel processors, respectively, at each stage.

Additionally, Table 3.2 shows the percentage decrease in the makespan, or relative superiority in the performance of the SPT rule as compared to the RANDOM priority rule, while Tables 3.3 and 3.4 demonstrates the same relationship for the MTWF and MWRF priority rule, respectively.

4.0 OBSERVATIONS AND CONCLUSIONS OF SIMULATION STUDY

The simulation study of the FSMP problem is a limited study in the sense that only two criteria are studied for the static representation. The results obtained provides general guidelines for the selection of the priority rules. The SPT priority rule is observed to be consistently superior to all other rules studied in the research for the mean flow time criteria. However, in the study of the makespan criteria, there is no clear superior and the study is more or less unconvincing for the percentage improvement in the makespan of contending priority rule over the RANDOM priority rule. Further observations and conclusions on the two measures of performance are summarized below in the following subsections.

4.1 MEAN FLOW TIME CRITERIA

The performance of the SPT priority rule has been observed to be consistently superior to all other rules studied in this simulation research for minimizing the mean

TABLE 3.2. PERCENTAGE DECREASE IN THE MAX. FLOW TIME OF THE SPT RULE w.r.t. THE RANDOM RULE.

n x m	NUMBER OF PARALLEL PROCESSORS				
	1	2	3	4	5
5 x 2	7.34	0.04	-1.6	-2.1	0
5 x 3	11.0	6.30	-0.8	-1.1	0
5 x 5	11.0	4.61	0.54	-1.3	0
5 x 7	7.30	1.30	0.80	-0.2	0
5 x 10	5.16	2.14	-0.0	0.14	0
5 x 20	3.67	2.44	0.56	-0.0	0
10 x 2	7.78	4.55	3.09	-1.7	2.20
10 x 3	9.96	5.49	5.35	2.64	0.65
10 x 5	9.51	6.21	3.91	2.68	0.86
10 x 7	9.18	6	2.91	1.12	0.16
10 x 10	7.22	3.85	2.63	1.49	0
10 x 20	5.43	3.99	2.38	0.93	0.81
15 x 2	6.32	5.11	2.31	2.17	2.03
15 x 3	10.0	8.68	5.17	2.91	2.04
15 x 5	12.1	8.60	5.71	4.20	2.78
15 x 7	9.48	7.31	4.80	2.90	2.70
15 x 10	8.81	5.33	4.48	2.58	2.13
15 x 20	4.68	5.17	4.43	1.57	1.14
20 x 2	6.62	5.91	3.31	2.47	0.59
20 x 3	10.0	6.98	6.31	2.78	3.46
20 x 5	9.95	9.64	7.32	6.56	3.33
20 x 7	10.9	8.57	5.21	5.47	4.32
20 x 10	10.0	8.44	5.99	3.68	1.59
20 x 20	5.81	4.89	3.73	2.61	1.80
30 x 2	5.00	5.11	4.03	3.48	3.13
30 x 3	9.98	6.93	6.01	4.83	3.85
30 x 5	10.8	8.06	7.16	5.12	4.51
30 x 7	11.7	9.20	8.21	5.67	5.74
30 x 10	9.44	6.61	7.55	5.12	4.51
30 x 20	7.22	6.14	4.90	3.43	2.65
50 x 2	4.45	3.74	4.25	2.31	3.88
50 x 3	7.13	6.83	5.32	4.72	4.03
50 x 5	9.97	8.56	8.75	6.39	5.57
50 x 7	10.1	9.98	8.35	6.33	6.25
50 x 10	9.85	8.71	7.69	7.52	6.40
50 x 20	8.13	6.53	5.60	5.03	4.14

TABLE 3.3. PERCENTAGE DECREASE IN THE MAX. FLOW TIME OF THE MTWF RULE w.r.t. THE RANDOM RULE.

n x m	NUMBER OF PARALLEL PROCESSORS				
	1	2	3	4	5
5 x 2	-0.8	5.28	4.29	2.68	0
5 x 3	0.18	6.26	3.40	2.42	0
5 x 5	2.44	3.19	2.11	0.96	0
5 x 7	-0.6	0.58	3.17	1.27	0
5 x 10	0.21	1.27	1.65	1.06	0
5 x 20	-0.6	2.62	1.53	0.41	0
10 x 2	0.28	2.13	6.34	6.41	10.5
10 x 3	-0.1	0.57	3.00	6.85	7.32
10 x 5	0.63	1.11	2.51	7.27	6.21
10 x 7	1.42	1.47	2.89	4.76	3.98
10 x 10	-0.2	0.09	3.51	4.28	2.85
10 x 20	0.95	1.68	2.73	2.71	2.25
15 x 2	1.00	1.97	3.58	5.76	7.16
15 x 3	-0.0	1.16	1.75	1.39	5.84
15 x 5	1.01	0.29	1.10	2.96	6.13
15 x 7	-0.5	0	-0.5	2.26	4.93
15 x 10	-0.3	-0.3	1.55	3.38	4.84
15 x 20	-0.2	0.74	2.64	3.54	3.82
20 x 2	0.82	1.59	2.97	3.80	4.13
20 x 3	2.51	0.77	1.78	2.54	4.14
20 x 5	-1.0	0.46	1.78	1.53	1.65
20 x 7	0.66	0.25	-1.0	0.39	3.39
20 x 10	0.36	1.01	0.61	1.66	2.62
20 x 20	0.64	-0.2	1.08	3.24	3.98
30 x 2	0.31	1.54	2.57	3.22	4.31
30 x 3	0.36	-0.2	0.73	2.25	1.75
30 x 5	0.87	0.20	0.11	0.86	1.53
30 x 7	0.02	0.70	0.63	0.31	1.81
30 x 10	0.03	-1.0	0.28	1.70	1.52
30 x 20	-0.1	1.24	0.43	0.68	2.08
50 x 2	0.87	0.84	1.33	1.83	2.61
50 x 3	0.48	0.98	1.34	1.66	1.34
50 x 5	0.58	0.75	0.38	0.04	0.76
50 x 7	-0.1	0.47	0.82	-0.1	0.48
50 x 10	0.32	0.85	0.01	0.49	0.74
50 x 20	0.41	0.17	0.24	0.49	1.49

TABLE 3.4. PERCENTAGE DECREASE IN THE MAX. FLOW TIME
OF THE MWRF RULE w.r.t. THE RANDOM RULE.

n x m	NUMBER OF PARALLEL PROCESSORS				
	1	2	3	4	5
5 x 2	-0.8	5.71	4.55	2.68	0
5 x 3	0.14	6.38	3.49	2.42	0
5 x 5	2.45	3.62	1.96	0.96	0
5 x 7	-0.8	0.39	3.15	1.27	0
5 x 10	0.38	1.49	1.67	1.06	0
5 x 20	-0.5	2.95	1.54	0.41	0
10 x 2	0.28	2.80	8.55	8.78	12.0
10 x 3	0.06	1.50	5.08	7.73	7.99
10 x 5	0.73	1.46	3.96	7.24	5.97
10 x 7	1.60	2.02	3.11	4.64	4.02
10 x 10	-0.0	0.01	3.82	4.55	2.94
10 x 20	0.92	1.19	2.57	2.67	2.18
15 x 2	1.00	2.60	4.91	8.32	10.5
15 x 3	0.12	2.14	3.73	4.24	8.88
15 x 5	1.04	0.54	1.96	4.65	6.46
15 x 7	-0.1	0.44	-0.6	3.18	4.79
15 x 10	-0.3	-0.6	1.63	3.33	5.22
15 x 20	-0.2	0.62	2.52	3.22	3.65
20 x 2	0.82	2.08	4.10	5.84	7.11
20 x 3	2.59	1.46	3.55	5.01	7.72
20 x 5	-1.0	1.01	2.67	3.87	3.42
20 x 7	0.80	0.82	-0.2	1.50	3.54
20 x 10	0.67	1.05	1.11	1.93	2.97
20 x 20	0.74	-0.2	1.02	3.15	4.10
30 x 2	0.31	1.78	3.31	4.53	6.33
30 x 3	0.49	0.19	1.84	4.44	5.42
30 x 5	1.06	0.66	1.12	2.75	3.70
30 x 7	0.12	0.86	1.61	1.03	3.55
30 x 10	0.03	-0.7	1.41	1.93	1.84
30 x 20	-0.0	0.76	0.28	0.77	2.04
50 x 2	0.87	1.03	1.75	2.75	3.84
50 x 3	0.33	1.48	2.34	2.96	3.37
50 x 5	0.65	1.11	1.55	1.30	2.97
50 x 7	-0.1	1.08	1.47	1.18	1.72
50 x 10	0.58	0.80	0.53	0.37	1.50
50 x 20	0.39	0.28	-0.0	0.46	1.35

flow time criteria. The notable challenge to this rule came from the LTWF rule and somewhat from the LWRF rule. Indeed for the large size problems, the superiority of SPT is clearly demonstrated. For the small size problems, the distinction is not very clear specially when the number of jobs approaches the number of parallel processors at each stage. This behavior should naturally be expected for a limited queuing takes place at each stage of processing, thereby increasing the possibility of reaching the best solution by random sequencing. Other observations include:

- The performance of the SPT in terms of the number of occurrences deteriorates with the increase in the number of stages for the same number of jobs and parallel processors. A similar trend is also noticed in the percentage improvement of the mean flow time using the SPT over the RANDOM priority rule.
- The performance of the SPT sequencing rule in terms of the number of occurrences improves with the increase in the number of parallel processors for the same number of jobs and machine stages. Quite surprisingly, the percentage improvement of the mean flow time using the SPT, over the RANDOM priority rule decreases for the same situation, most likely because of the availability of alternate routes.
- The performance of the SPT priority rule in terms of the number of occurrences declines by the increase in the number of jobs for the same number of machine

stages and parallel processors. However, the trend is inconclusive in terms of the percentage decrease in the average value of the mean flow time of the SPT over the RANDOM priority rule.

- For $(M_j / n \times m) > 0.01$, the SPT priority rule is generally a good choice for $M_j > 1$. Also, for $(M_j / n \times m) < 0.01$, the LTWF priority rule becomes a good contender.

4.2 MAKESPAN CRITERIA

The results of the simulation study for the makespan criteria are not as apparent as that for the mean flow time. The SPT rule, however, is distinctively superior to all other sequencing rules considered in the case of a pure flow shop, i.e., $M_j = 1$ for all j. It also performs better than others when the number of jobs to the number of parallel processors ratio is large and when the number of stages is large. In other situations, the MWRF rule dominates others with the MTWF rule following closely (as opposed to LWRF and LTWF rules for the mean flow time criteria). Surprisingly, the LPT rule, which heuristically gives the best makespan in the parallel machines scheduling, never became a viable contender except in the situation when the number of jobs approaches the number of parallel processors. Even in such situations, the results compared marginally or worst than the ones for the RANDOM priority rule. Some of the other observations include:

- The performance of the SPT sequencing rule in terms of the number of occurrences improves steadily with the increase in the number of jobs, however, it sharply decreases with the increase in the number of parallel processors at each stage.
- The performance of the SPT priority rule in terms of the percentage decrease in the average makespan over the RANDOM rule, decreases with the increase in the number of parallel processors at each stage.
- The performance of the MTWF and MWRF priority rules in terms of the number of occurrences improves steadily with the increase in the number of parallel processors and decreases sharply with the increase in the number of jobs.
- The performance of the MTWF and MWRF priority rules is not significantly better than the RANDOM rule in terms of the average makespan. This is in spite of the fact that these rules dominates the RANDOM priority rule in terms of the number of occurrences.

5.0 FURTHER EXTENSIONS

There are other measures of performance such as mean tardiness and maximum tardiness which have not been studied in this research. A similar simulation study of a FSMP is recommended for such criteria. However, for additional measures of performance, such as the ones mentioned above, other appropriate priority rules must also be considered.

In addition, some hybrid priority rules may be developed and studied further for a similar or extended study of the FSMP scheduling problem.

Moreover, the essence of simulation study is more closely captured in a dynamic study of the problem. Therefore, a dynamic study of a FSMP is recommended for mean flow time, mean tardiness, maximum tardiness, and other measures of performance. Such a study will provide a closer look at the large scale scheduling problem of a FSMP.

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CHAPTER IV

PREDICTION OF NSTS FLIGHT RATE

EXECUTIVE SUMMARY
MASTERS PROJECT OF CAPT. R. A. RONCACE
PREDICTION OF NSTS FLIGHT RATE
BY JLH 6 OCT 88

The purpose of this paper is to develop a methodology to predict the flight rate of the shuttle based on the premise that JSC can support anything that KSC can fly. To this end the historical processing times at KSC are used as the basis for the predictions. The paper uses a two pronged approach to determine flight rate. One method used is to apply a Weibull distribution to historical times and then run a simulation for 50 sets of 50 flows. Another is to assume that a learning curve is in effect and to look at flights 41 through 60. In both methods, the first orbiter flight in 81 is ignored and the remaining 24 processing flows are separated into 17 normal flows and 7 anomalies (page 6 or Table 1).

Several caveats are made: the effects of the Challenger accident are not taken into account and neither are facility conflicts at KSC or launch window constraints. Additionally, the following assumptions are made in the work: The SCA and MLP are always available, each flight is 7 days in duration, a return from Edwards takes 5 days, 50% of the landings are at Edwards, and anomalies amount to 1/4 of the total flows.

The results are shown in the following table:

Learning Curve Results

work days/week	days/year	optimistic	pessimistic
7 days/week	365	23.4 flts/yr	14.2 flts/yr
6 days/week	312	20.0 flts/yr	12.1 flts/yr
5 days/week	260	16.7 flts/yr	10.1 flts/yr
5/week + 10 holidays	250	16.0 flts/yr	9.7 flts/yr

Statistical Results

days/year	95 % confidence interval	90% confidence interval
365	14.94 to 14.77	14.93 to 14.76
312	12.77 to 12.62	12.76 to 12.63
260	10.64 to 10.52	10.63 to 10.53
250	10.23 to 10.11	10.22 to 10.12

The conclusions of the paper (page 22-23) are worth reading in their entirety. The main conclusion is, because of the optimistic nature of the higher numbers, that NSTS will have "only marginal capability to meet the planned maximum sustained flight rate of 14 flights per year, and only then if significant learning curve progress can be sustained and/or work schedules allowing few holidays and down weekends are used over long periods of time."

INDE 6398

MASTERS PROJECT

PREDICTION OF NATIONAL SPACE TRANSPORTATION SYSTEM FLIGHT RATE BY ANALYSIS OF SPACE SHUTTLE PROCESSING FLOW EXPERIENCE

BY

ROBERT A. RONCACE

A paper submitted in partial fulfillment
of the requirements for the degree of
M. S. I. E. w/Engineering Management Option

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Table of Contents

I. Introduction.

I.A. Purpose.

The purpose of this paper is to develop and apply a methodology to predict the flight rate of the National Space Transportation System (NSTS).

I.B. Background.

Since the loss of the Space Shuttle Challenger in early 1986, it has been generally realized in NASA and the aerospace industry that Shuttle flights would be in short supply in the years to come. Flight assignments for major payloads have therefore been strictly controlled based on National priority. Department of Defense missions and National science missions have first priority. Virtually all commercial payloads with the capability of flying to space on an expendable booster have been forced to seek such an alternative to the Shuttle.

As the mix of payloads has changed, so has the relative importance of schedule slippage. Delays in the launch of DoD missions may handicap our national technical means of intelligence gathering and arms control verification. Delayed science missions mean slow downs and cost increases for many programs, including, but not limited to, the US Space Station. With such national interests at stake it is critically important for an operational space launch capability to meet it's advertised schedule, or conversely, to only advertise a schedule that can be met.

The flight rate of the National Space Transportation System (NSTS) is literally the number of Space Shuttle flights flown in a particular period of time. The time period of interest here is the Fiscal year, since this is the planning time unit normally used by NASA for long range planning.

Despite the Space Shuttle´s many notable accomplishments, the flight rate of the NSTS has never reached it´s intended maximum. The original NSTS Program Plan predicted as many as 48 flights per year, eventually. This estimate was reduced several times during the development and early years of NSTS operations. By November 1985 the maximum expected flight rate had been reduced to 24 flights per year, to be achieved in Fiscal year 1989 [1]. In the nearly five years of NSTS operations (up through the Challenger accident) there have been only 25 Space Shuttle missions launched. The most flights launched in one year was ten. This occurred in the calendar year immediately preceding the Space Shuttle Challenger accident and included the last Challenger launch.

Current plans call for a quick buildup, once flight operations resume in late 1988, to 10 flights in FY90 [2], increasing to a maximum sustained flight rate of 14 per year in FY94 [3]. This flight rate assumes delivery of the fifth orbiter in 1991 to replace Challenger. Continuous upgrades to the Shuttle processing facilities at Kennedy Space Center (KSC) are also planned throughout the period since these facilities were never considered adequate to support the planned flight rate. Given the past inability to meet the program plan flight rate and the current sensitivity to delays in the flight schedule, a method of making a realistic estimate of potential NSTS flight rate must be developed.

The flight rate predictions made in this paper are based on the assumption that preparation of the flight hardware controls the possible flight rate. The process of preparing the Space Shuttle hardware for flight is accomplished at the Kennedy Space Center (KSC) at Cape Canaveral, Florida. Although the flight planning activities performed at the NASA L.B. Johnson Space Center in Houston, Texas, require more time than the hardware preparation at KSC, the activities at JSC are not seen as the "long pole in the tent."

Johnson Space Center´s products are primarily in the areas of payload and flight planning, shuttle flight software production and astronaut training. These activities are believed to be sufficiently flexible to support whatever hardware preparation schedule KSC could achieve.

The premise of this paper is that analysis of the past flight preparation experience data from KSC should allow a practical estimation of the achievable future NSTS flight rate. The sequence of activities done at KSC on the Space Shuttle Orbiter, it´s Boosters, and External Tank (collectively called a "stack" once mated together) to prepare each mission is called a processing flow. Every Space Shuttle mission is processed through the same ground facilities in the same order. These facilities are, in order, the: Orbiter Processing Facility (OPF), Vehicle Assembly Building (VAB), and the Launch Pad (Pad). Figure 1 illustrates the Space Shuttle Processing Flow.

This paper explores two methods of making NSTS flight rate estimates, both incorporating simplified simulations of the Shuttle processing flows. The first utilizes statistical prediction of processing times. To do this, appropriate statistical distributions will be fit to the cumulative Shuttle processing experience. These statistical distributions will then be used to randomly generate additional Shuttle hardware processing flows to simulate the system. The mean flight rate of the the NSTS will be calculated from the results of the simulation.

The second analysis method predicts processing times by the application of learning curve theory. In this method, the cumulative Shuttle processing experience will again be examined, but this time in chronological order. The presence of learning curve effects will be visible in reduced flow processing times as experience increases. Learning curves will be fit to this data to determine the learning rate. Once the learning rate is known (and assuming the rate remains constant) the theoretical processing time of any Shuttle mission may be calculated. The local mean theoretical processing time may be calculated by examining several flows prior to and after

SPACE SHUTTLE PROCESSING FLOW

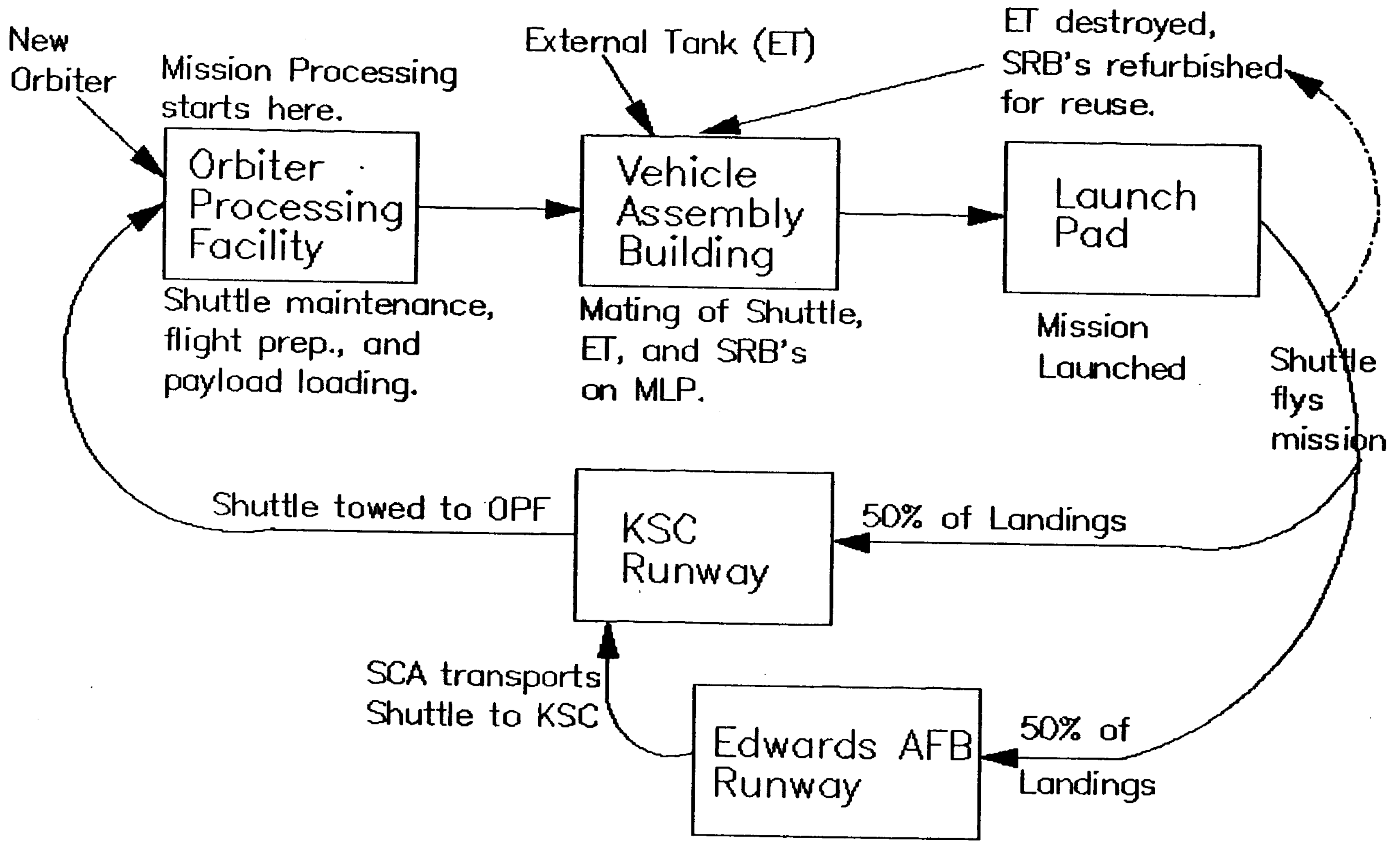


Figure 1

the one of interest. And from the mean flow processing time the mean flight rate may be calculated.

Though initially straightforward, the above methods of analysis rapidly become complicated when the actual flow processing experience is examined. The reason for the complication lies in the simple fact that no two Shuttle missions or processing flows are alike. Though the facilities and their processing order are always the same, that is not to say that exactly the same processing actions occur each time the Shuttle is prepared to fly.

From one processing flow to the next the actions accomplished in these facilities are tailored to meet the needs of the mission being prepared and the maintenance requirements of the particular Shuttle orbiter vehicle. Though they outwardly appear identical, the three remaining Shuttles are not the same, either in equipment or capability. Perhaps the most glaring example, Columbia, the first Shuttle, has an empty weight approximately 8,000 pounds greater than her sisters, Discovery and Atlantis. Columbia's extra weight is caused by the presence of additional structure and flight instrumentation found to be unnecessary for the later Shuttles after the Columbia's test program was completed.

The above is just the most obvious example, but many other less obvious, though no less important, physical differences exist between these highy complex, yet largely hand made spacecraft. These differences directly influence the work needed to prepare the shuttles for flight.

Therefore, flight rates may not be extrapolated from the results of a single processing flow.

I.C. Normal Flows and Anomaly Flows:

The first Space Shuttle flight occurred during April, 1981, using the Orbiter Vehicle "Columbia" (all of the Shuttles are known as "Orbiter Vehicles" (OV); Columbia is assigned the designator: OV-102). The first mission is not considered in this analysis because the types and quantities of preparation for the first mission were unique compared to the other missions. The first mission's processing flow was uniquely long even compared to the first flows of the other orbiters: "Challenger"; OV-099, "Discovery"; OV-103, and "Atlantis"; OV-104.

Of the remaining 24 Shuttle processing flows, seven have been identified as anomalies. They are considered anomalies because their processing times were unusually long compared to the trends presented by the other flows at the time. These anomalous flows will undergo the same analysis as the 17 normal flows but will be treated separately. The seven anomalies include: the other three "first flows" (one each for the other three orbiters), the first flow for OV-102 after overhaul, two Spacelab flows (complicated missions and the first of their kind), and mission number 2 (which had unique inspection requirements associated with the processing flow). Table 1 shows the normal and anomaly flows and the processing times data experienced in the facilities at KSC [4].

Table 1

KSC SHUTTLE PROCESSING FLOW DATA
(Workdays)

"Normal Flows"

Mission Seq #	STS- No.	Orbiter OV-	FACILITY PROCESSING TIMES				Flight Dur	Notes
			OPF	VAB	Pad	Total		
3	3	102	55	12	30	97	8.00	%
4	4	102	41	7	29	77	7.05	
5	5	102	48	9	45	102	5.09	
7	7	99	34	5	21	60	6.10	
8	8	99	26	4	25	55	6.05	
10	41-B	99	52	6	22	80	7.97	
11	41-C	99	31	4	18	53	6.99	
13	41-G	99	53	5	22	80	8.22	
14	51-A	103	34	5	17	56	7.99	
15	51-C	103	31	5	20	56	3.06	
16	51-D	103	53	5	15	73	7.00	
18	51-G	103	37	7	14	58	7.07	
19	51-F	99	39	5	31	75	7.95	&
20	51-I	103	27	7	22	56	7.10	
22	61-A	99	35	4	14	53	7.03	&
23	61-B	104	27	4	15	46	6.88	
25	51-L	99	30	5	28	63		@

"Anomaly Flows"

Mission Seq #	STS- No.	Orbiter OV-	FACILITY PROCESSING TIMES				Flight Dur	Notes
			OPF	VAB	Pad	Total		
1	1	102	531	33	104	668	2.26	$
2	2	102	99	18	70	187	2.26	**
6	6	99	123	6	115	244	5.02	*
9	9	102	82	12	34	128	10.32	&
12	41-D	103	123	15	72	210	6.04	*
17	51-B	99	88	12	32	132	7.01	&
21	51-J	104	84	14	34	132	4.07	*
24	61-C	102	101	8	34	143	6.09	#

Key to Notes:

% All Flight Durations are given in calendar days.
& Spacelab mission.
@ Flight duration N/A.
$ OV-102 first flow - not used in this analysis.
** OV-102 second flow.
* First flow for this Orbiter.
# First flow for OV-102 after overhaul.

References:

- Processing Flow Times; Ref #4.
  Flight Durations; Ref #10.

I.D. Caveats and Assumptions.

Before beginning this study several additional caveats and assumptions must be stated:

Caveat 1: This study does not examine the effects of the additional procedures which have been incorporated into the Shuttle processing flow since the Space Shuttle Challenger accident. Those additions will have the effect of increasing the time required to process the Space Shuttle for flight. Thus the results of this study will likely prove to be optimistic compared with the current capabilities of the NSTS.

Caveat 2: The simulations employed in this study do not account for facility conflicts at KSC. Extended delays between missions due to launch window constraints are also not accounted for. Both of these considerations would have the effect of reducing the potential flight rate, making the results of the simulations optimistic.

Assumption 1: It was assumed for this study that the Shuttle Carrier Aircraft (SCA) and the Mobile Launcher Platform (MLP) were always available when needed. The SCA is a modified Boeing-747 aircraft capable of carrying the Space Shuttle piggyback. Whenever the Shuttle returns from a space mission to a landing at Edwards Air Force Base or White Sands Space Harbour, the SCA is used to ferry the Space Shuttle back to KSC for maintenance and processing. Only one SCA is currently available, although another is on order. Loss or breakdown of the SCA could disrupt the Shuttle flight schedule since at least 50-percent of future

Shuttle missions are expected to land at Edwards AFB.

The MLP is a massive four-tracked land crawler used to move the fully assembled Shuttle "stack" from the VAB to the launch Pad. The trip only requires about one day to complete, but the MLP is fully occupied in the VAB for mating (stacking) of the External Fuel Tank, Solid Rocket Boosters, and the Shuttle, for as much as several weeks before the stack is moved to the Pad. Two MLP's are now available and a third is on order, but loss or breakdown of one of the existing MLP's would delay the flight schedule.

Assumption 2: Several assumptions were made for the simulations concerning the duration of flight, the fraction of the landings to be made at KSC, and the time required to ferry an orbiter to KSC from an Edwards AFB landing. The flight duration was assumed to be seven days for all flights. In fact, the flight duration is a function of many factors, only the more obvious of which are: orbit inclination, orbit altitude, landing site selection, payload requirements, weather considerations, and problems experienced during the mission. Perhaps the only definite thing that can be stated is the mission duration will not be exactly what is planned. Since approximately seven days was the most common flight duration of the current mission experience (see Table 1), and seven days is the standard mission duration for planning purposes, we use this value for our simulation.

Like the situation with the flight duration, the time to return the orbiter to KSC from an Edwards AFB landing will have it´s own unique distribution. Five days is the planned time so we will use this value directly, on the assumption that deviations will be normally distributed about the mean and will have no effect over the long term.

The 50-percent fraction of the landings expected to occur at Edwards AFB is based on the current NSTS long range program plan. But all landings will be made at Edwards AFB for the first several missions after resumption of flight activities in late 1988. Therefore the application of these simulations to early flights will not have taken into account the expected greater than 50-percent landings at Edwards AFB. The simulations results may yield an optimistic flight rate for this reason.

Assumption 3: Anomaly flows were assumed to occur at a ratio of approximately one-quarter of the total number of flows, or 1 anomaly : 3 normal flows. The actual ratio experienced was 7 anomaly : 17 normal flows, or 1 : 2.43. Recent NSTS management decisions have reduced the number of relatively simple commercial deployment missions compared to the number of complicated Spacelab and other science missions. However, the future of this policy is certainly subject to change. What is known is that the new, replacement orbiter is expected to be delivered for it´s first flow in 1991 and all of the orbiters will periodically experience long processing flows to allow overhauls, inspections, and modifications. Thus the assumed ratio may be a slightly optimistic assumption and may yield optimistic flight rate results.

II. Flight Rate Estimation Using Statistical Distributions.

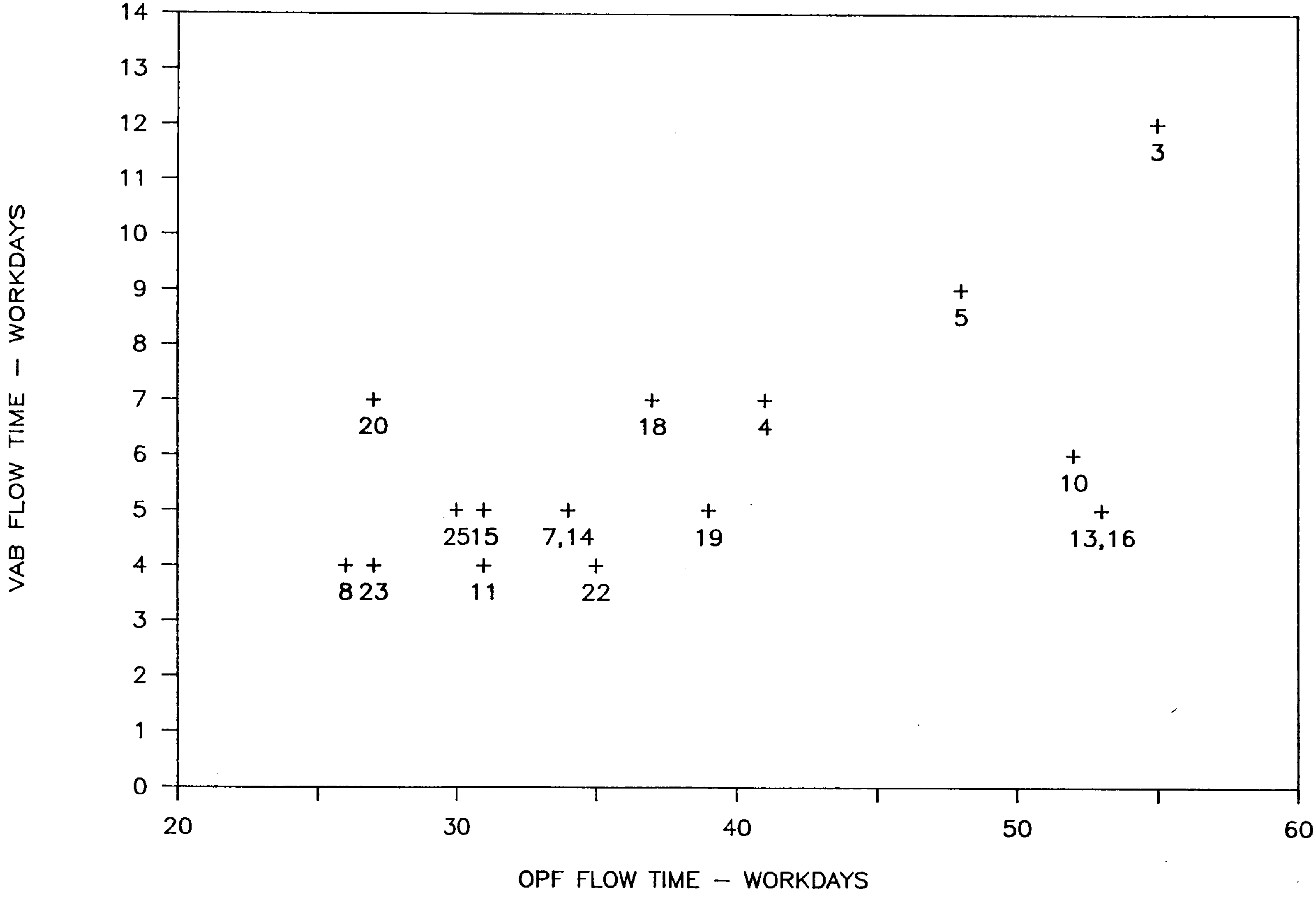
II.A. Assessment of Correlation Factors Between Facilities.

The purpose of this section is to establish whether the processing times for the several facilities are independent, or if there is some causal relationship between the facilities. If the OPF, VAB, and Pad facilities have processing times with no relationship among them it will be possible to fit statistical models to the facility time histories and randomly generate flow times for the individual facilities. Otherwise it will be necessary to simulate the process using some statistical model of the total flow (the sum of the times for the three facilities for each flow) process time histories.

Figures 2 and 3 are scatter plots of the KSC facility time histories showing the individual facilities compared with their next serial partner in the flow. That is, OPF vs VAB and VAB vs Pad. These data are displayed in the original pairings as they occurred. Although there is significant scattering of the data some relationships appear to exist for the Normal Flows.

Figure 2a displays OPF vs VAB processing time for the normal flows. Though not easily defined, there appears to be a relationship causing VAB processing time to increase as OPF processing time increases. A similar trend is apparent implying increased Pad processing time as VAB processing time increases, as shown in Fig 2b.

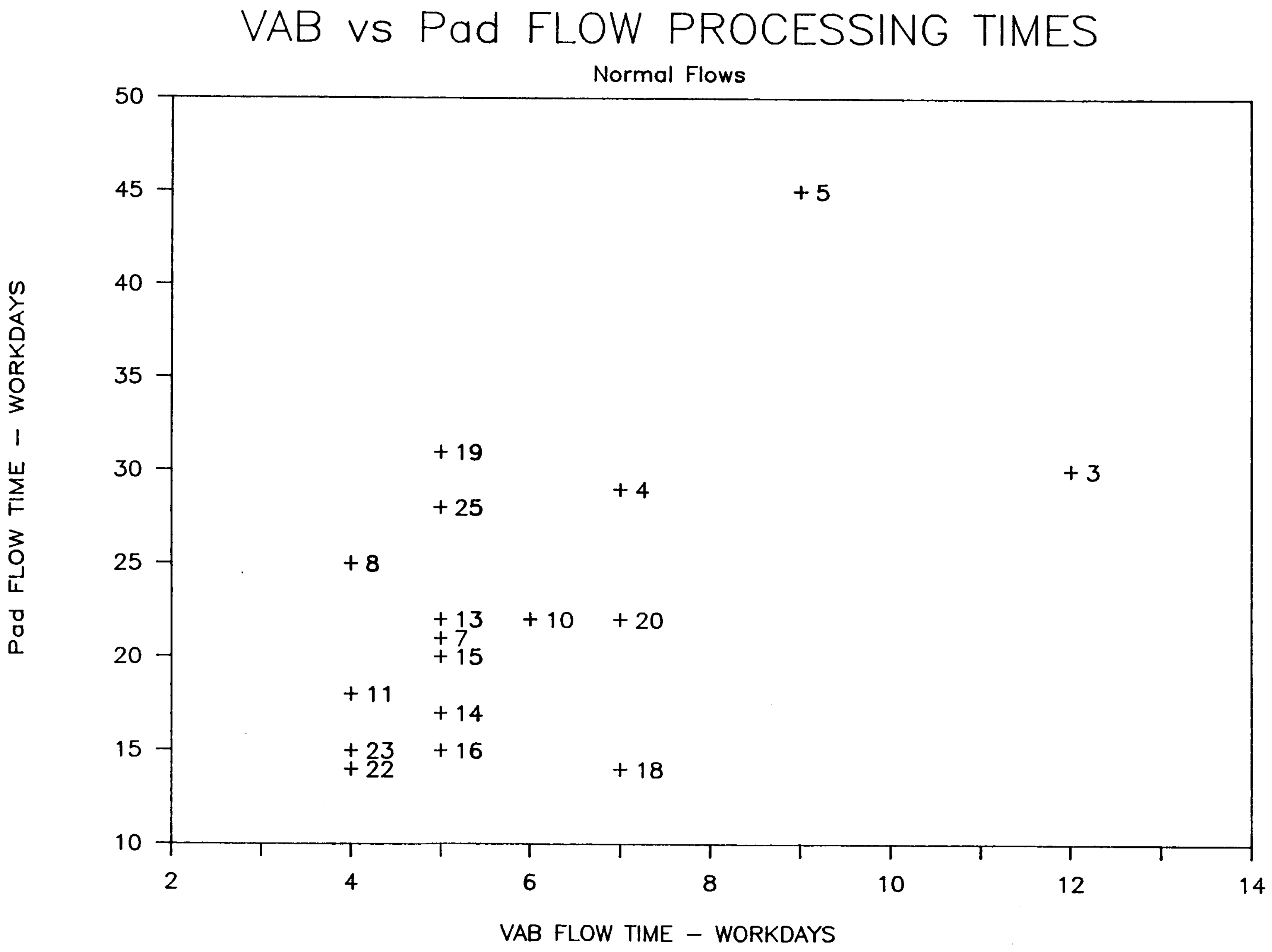
For the Anomaly flows no such trends are readily



OPF vs VAB FLOW PROCESSING TIMES

Normal Flows

Figure 2a



VAB vs Pad FLOW PROCESSING TIMES

Normal Flows

Figure 2b

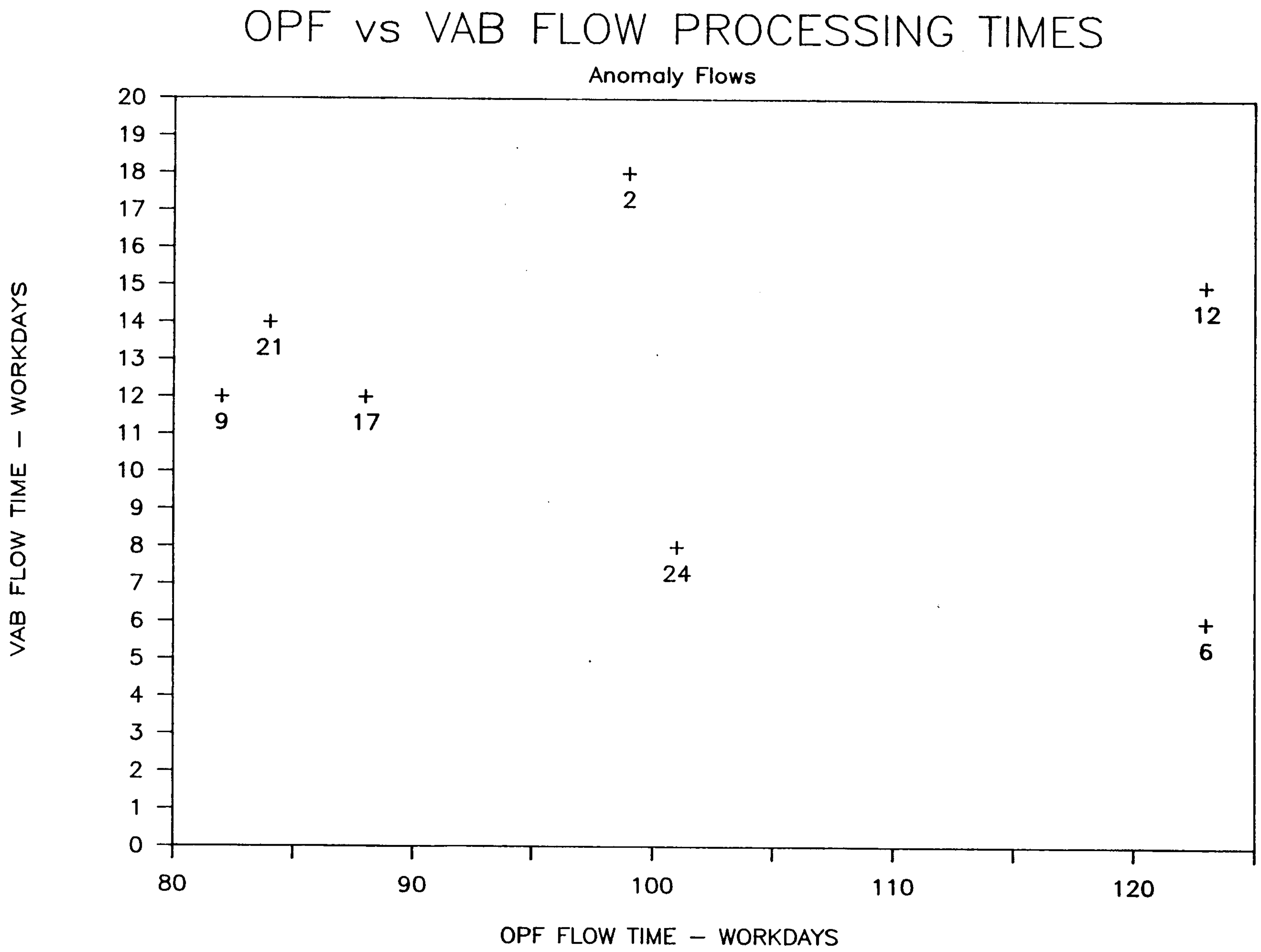

OPF vs VAB FLOW PROCESSING TIMES
Anomaly Flows
VAB FLOW TIME – WORKDAYS
OPF FLOW TIME – WORKDAYS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
80
90
100
110
120
9
21
17
2
24
12
6

Figure 3a

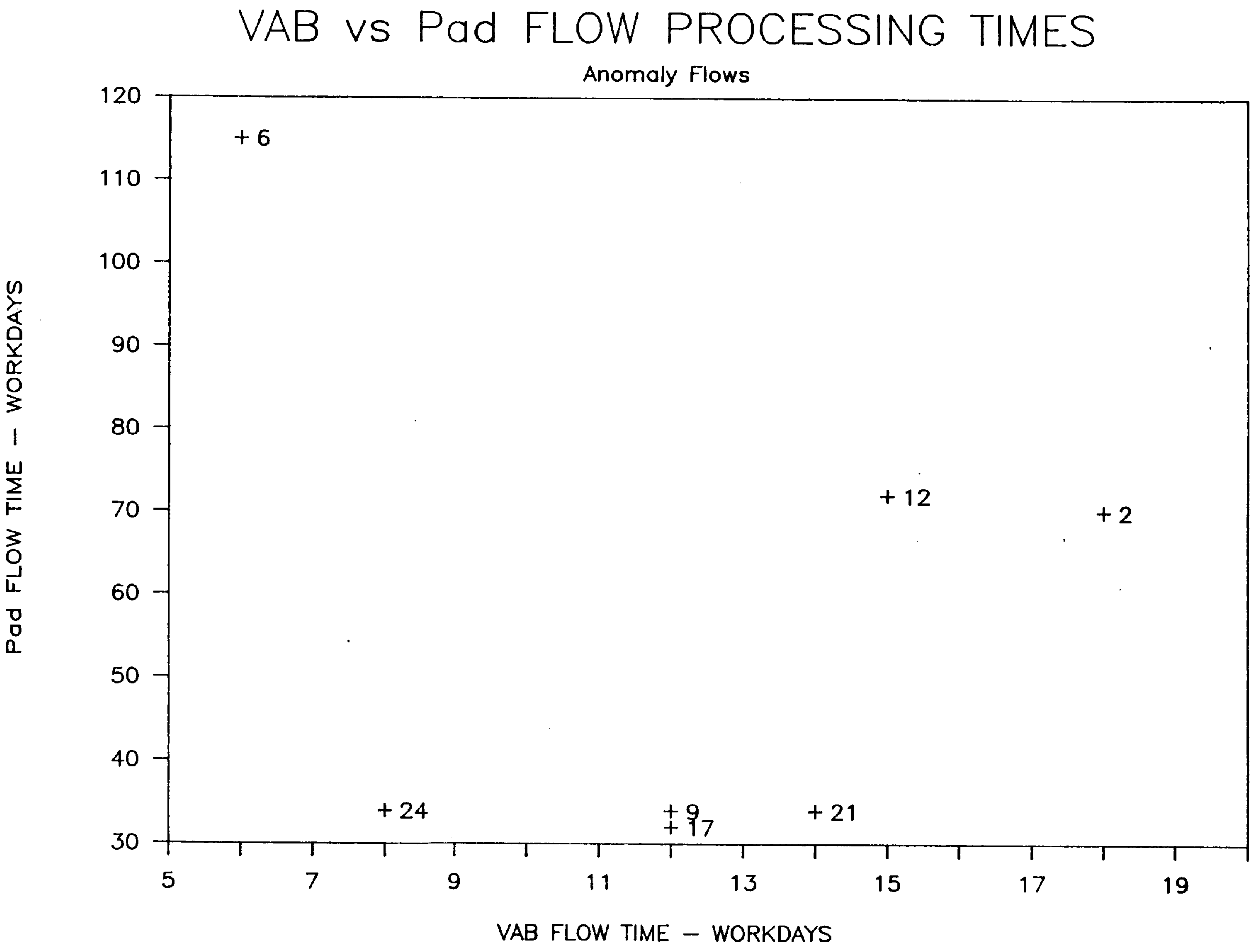

VAB vs Pad FLOW PROCESSING TIMES
Anomaly Flows
Pad FLOW TIME – WORKDAYS
120
110
100
90
80
70
60
50
40
30
VAB FLOW TIME – WORKDAYS
5
7
9
11
13
15
17
19
+ 6
+ 12
+ 2
+ 24
+ 9
+ 17
+ 21

Figure 3b

apparent. As shown in Figs. 3a and b considerably more data scatter is present for the Anomaly flow cases than for the Normal flow cases. If a causal relationship exists between the KSC facilities processing times for the Anomaly flows it is not visible to the naked eye.

To establish the validity of these observations, an assessment of the correlation factors between the facilities is accomplished in the manner outlined by Miller and Freund [5]. In this method, the sample correlation coefficient r is evaluated as:

$$r = S_{xy} / \sqrt{(S_{xx} S_{yy})},$$

where $S_{xx} = n \sum x_i^2 - (\sum x_i)^2$

$S_{yy} = n \sum y_i^2 - (\sum y_i)^2$

$S_{xy} = n \sum x_i y_i - (\sum x_i) (\sum y_i)$

and n = the number of data points.

Having calculated r, the null hypothesis, H_o, that the actual correlation coefficient, $\rho=0$ may be tested at the desired level of significance, α, using the relation

$$z = Z \cdot \sqrt{(n-3)}$$

with the value of Z being obtained from an appropriate table or from the expression

$$Z = 1/2 \cdot \ln((1+r)/(1-r)).$$

The H_o must be rejected if z calculated as above is greater than $z_{\alpha/2}$ from a standard normal table.

The results of this analysis are given in Table 2 and show that for the Normal flows we must reject the H_o (with significance level $\alpha= 0.05$) that the correlation coefficient, $\rho=0$ for both OPF vs VAB and VAB vs Pad. Thus

Table 2a

Test of Null Hypothesis, Ho.
Ho: correlation coefficient, $\rho=0$.

"Normal Flows"

Mission Seq No.	OPF x	VAB y	x^2	y^2	xy
3	55	12	3025	144	660
4	41	7	1681	49	287
5	48	9	2304	81	432
7	34	5	1156	25	170
8	26	4	676	16	104
10	52	6	2704	36	312
11	31	4	961	16	124
13	53	5	2809	25	265
14	34	5	1156	25	170
15	31	5	961	25	155
16	53	5	2809	25	265
18	37	7	1369	49	259
19	39	5	1521	25	195
20	27	7	729	49	189
22	35	4	1225	16	140
23	27	4	729	16	108
25	30	5	900	25	150
SUM=	653	99	26715	647	3985

n= 17

Sxx= 27746
Syy= 1198
Sxy= 3098

r= 0.537
Z= 0.600
z= 2.25

For confidence level $\alpha=0.05$, $z_{\alpha/2}=1.96$ (see Ref 8). Since z calculated above is greater than 1.96 we must reject the Ho that the correlation coefficient, $\rho=0$.

Table 2b

Test of Null Hypothesis, Ho.
Ho: correlation coefficient, ρ=0.

"Normal Flows"

Mission Seq No.	VAB x	Pad y	x^2	y^2	xy
3	12	30	144	900	360
4	7	29	49	841	203
5	9	45	81	2025	405
7	5	21	25	441	105
8	4	25	16	625	100
10	6	22	36	484	132
11	4	18	16	324	72
13	5	22	25	484	110
14	5	17	25	289	85
15	5	20	25	400	100
16	5	15	25	225	75
18	7	14	49	196	98
19	5	31	25	961	155
20	7	22	49	484	154
22	4	14	16	196	56
23	4	15	16	225	60
25	5	28	25	784	140
SUM=	99	388	647	9884	2410

n= 17

Sxx= 1198
Syy= 17484
Sxy= 2558

r= 0.559
Z= 0.631
z= 2.36

For confidence level α=0.05, $z_{\alpha/2}$ =1.96 (see Ref 8). Since z calculated above is greater than 1.96 we must reject the Ho that the correlation coefficient, ρ=0.

Table 2c

Test of Null Hypothesis, Ho.
Ho: correlation coefficient, ρ=0.

"Anomaly Flows"

Mission	OPF	VAB			
Seq No.	x	y	x^2	y^2	xy
2	99	18	9801	324	1782
6	123	6	15129	36	738
9	82	12	6724	144	984
12	123	15	15129	225	1845
17	88	12	7744	144	1056
21	84	14	7056	196	1176
24	101	8	10201	64	808
SUM=	700	85	71784	1133	8389

n= 7

Sxx= 12488 r= -0.262
Syy= 706 Z= -0.268
Sxy= -777 z= -0.54

For confidence level α=0.05, $z_{\alpha/2}$ =1.96 (see Ref 8). Since z calculated above is less than 1.96 we cannot reject the Ho that the correlation coefficient, ρ=0.

Table 2d

Test of Null Hypothesis, Ho.
Ho: correlation coefficient, ρ=0.

"Anomaly Flows"

Mission Seq No.	VAB x	Pad y	x^2	y^2	xy
2	18	70	324	4900	1260
6	6	115	36	13225	690
9	12	34	144	1156	408
12	15	72	225	5184	1080
17	12	32	144	1024	384
21	14	34	196	1156	476
24	8	34	64	1156	272
SUM=	85	391	1133	27801	4570

n= 7

Sxx= 706
Syy= 41726
Sxy= -1245

r= -0.229
Z= -0.234
z= -0.47

For confidence level α=0.05, $z_{\alpha/2}$ =1.96 (see Ref 8). Since z calculated above is less than 1.96 we cannot reject the Ho that the correlation coefficient, ρ=0.

we must conclude that the individual facility processing times have some significant relationship between them and cannot be simulated individually.

The individual facility processing times for the Anomalous flows appear to have no significant relationship since we were unable to reject the H_o, above. This allows us to simulate the facility flow times for the Anomaly cases individually if we desire. But we are already constrained to use the total flow for the Normal case and therefore will not profit by simulating the individual facilities for the Anomaly case.

II.B. Weibull Statistical Distribution Fitted to Facility Processing Times.

When the cumulative experience in the processing facilities at KSC is plotted in ascending order of time (workdays) required, the result is a cumulative histogram of the processing flow experience. The three-parameter Weibull distribution is fitted to this data to provide the desired means to determine processing time confidence intervals.

Kapur and Lamberson [6] give the cumulative form of the three-parameter Weibull distribution as:

$$F(x; \theta, \beta, \delta) = 1 - \exp-[(x-\delta)/(\theta-\delta)]^{\beta}, \quad x>=\delta$$

where $\beta>0$, $\theta>0$, and $\delta>=0$. The Weibull slope or shape parameter is β; the scale parameter or the characteristic life is θ; and the minimum life or location parameter is δ. For the purposes of this analysis the parameter δ

represents the minimum processing time associated with a particular facility or total flow time. To fit the Weibull distribution to the data, the shape and scale parameters and the minimum processing time are allowed to vary in value until a best fit of the data is obtained.

The quality of the Weibull curve fit for the total facility processing time histories (for both the normal and the anomalous flows) is measured by the Kolmogorov-Smirnov (KS) goodness of fit test. The Weibull distributions fit to these data are all evaluated at the 0.20 significance level (that is, we are willing to accept a 20% chance of discarding an acceptable fit). The results of the Weibull fits are summarized in Tables 3 and 4, along with the maximum KS statistic determined from each curve fit and the critical value corresponding to the KS significance level as given by Mann et al [7]. Figures 4 and 5 show the Weibull distributions fitted to the facility time history data.

II.C. Simulation of the KSC Shuttle Processing Flow.

Using the Weibull distributions previously fit to the Normal and Anomaly flow times, above, we now are able to simulate the processing of shuttle missions to experimentally establish the flight rate.

The expression for the cumulative Weibull distribution may be conveniently reorganized to generate flow processing times given the input of a uniformly distributed random variate. From before we have the cumulative Weibull:

Table 3

Weibull Curve Fits and Goodness-of-Fit Test
"Normal Flows"

WEIBULL PARAMETERS		#FLOWS	TIME	Fn	Weibull	Abs Diff
Theta	67.79		20	0.000	0.000	
Beta	1.20		45		0.000	
Delta	45	1	46	0.059	0.023	0.036
		2	53	0.176	0.248	0.071
#flights	17	1	55	0.235	0.311	0.075
		3	56	0.412	0.341	0.071
		1	58	0.471	0.399	0.071
		1	60	0.529	0.454	0.075
		1	63	0.588	0.529	0.059
			64		0.552	
			66		0.596	
			68		0.636	
			71		0.690	
			72		0.706	
		1	73	0.647	0.722	0.075
		1	75	0.706	0.751	0.045
		1	77	0.765	0.777	0.013
			78		0.790	
			79		0.801	
		2	80	0.882	0.812	0.070
			82		0.833	
			84		0.851	
			86		0.868	
			89		0.889	
			90		0.896	
			92		0.908	
			94		0.918	
			96		0.928	
		1	97	0.941	0.932	0.009
			98		0.936	
			100		0.944	
		1	102	1.000	0.950	0.050
			104		0.956	
			106		0.962	
			108		0.966	
			110		0.970	
			112		0.974	
			114		0.977	
			116		0.980	
			118		0.982	
			120		0.985	
		17			MAXDIFF=	0.075

For Alpha=0.2 and n=17, the Kolmogorov-Smirnov critical value =0.169 (see Ref 7). Because the MAXDIFF is less than the critical value we cannot reject the Ho that the sample came from a Weibull distribution with parameters given above.

Table 4

Weibull Curve Fits and Goodness-of-Fit Test
"Anomaly Flows"

WEIBULL PARAMETERS		#FLOWS	TIME	Fn	Weibull	Abs Diff
Theta	159.52		105		0.000	
Beta	1.20		110		0.000	
Delta	110		115		0.062	
			120		0.136	
#flights	7		125		0.212	
		1	128	0.143	0.257	0.114
		2	132	0.429	0.315	0.114
			140		0.422	
		1	143	0.572	0.459	0.113
			150		0.539	
			155		0.590	
			160		0.636	
			165		0.678	
			170		0.716	
			175		0.750	
			180		0.780	
		1	187	0.714	0.817	0.103
			190		0.831	
			195		0.852	
			200		0.871	
			205		0.888	
		1	210	0.857	0.902	0.045
			215		0.915	
			220		0.926	
			225		0.936	
			230		0.945	
			235		0.952	
			240		0.959	
		1	244	1.000	0.963	0.037
			250		0.969	
			255		0.973	
			260		0.977	
			265		0.980	
			270		0.983	
			275		0.986	
			280		0.988	
			285		0.989	
			290		0.991	
			295		0.992	
			300		0.993	
		7			MAXDIFF=	0.114

For Alpha=0.2 and n=7, the Kolmogorov-Smirnov critical value =0.247 (see Ref 7). Because the MAXDIFF is less than the critical value we cannot reject the Ho that the sample came from a Weibull distribution with parameters given above.

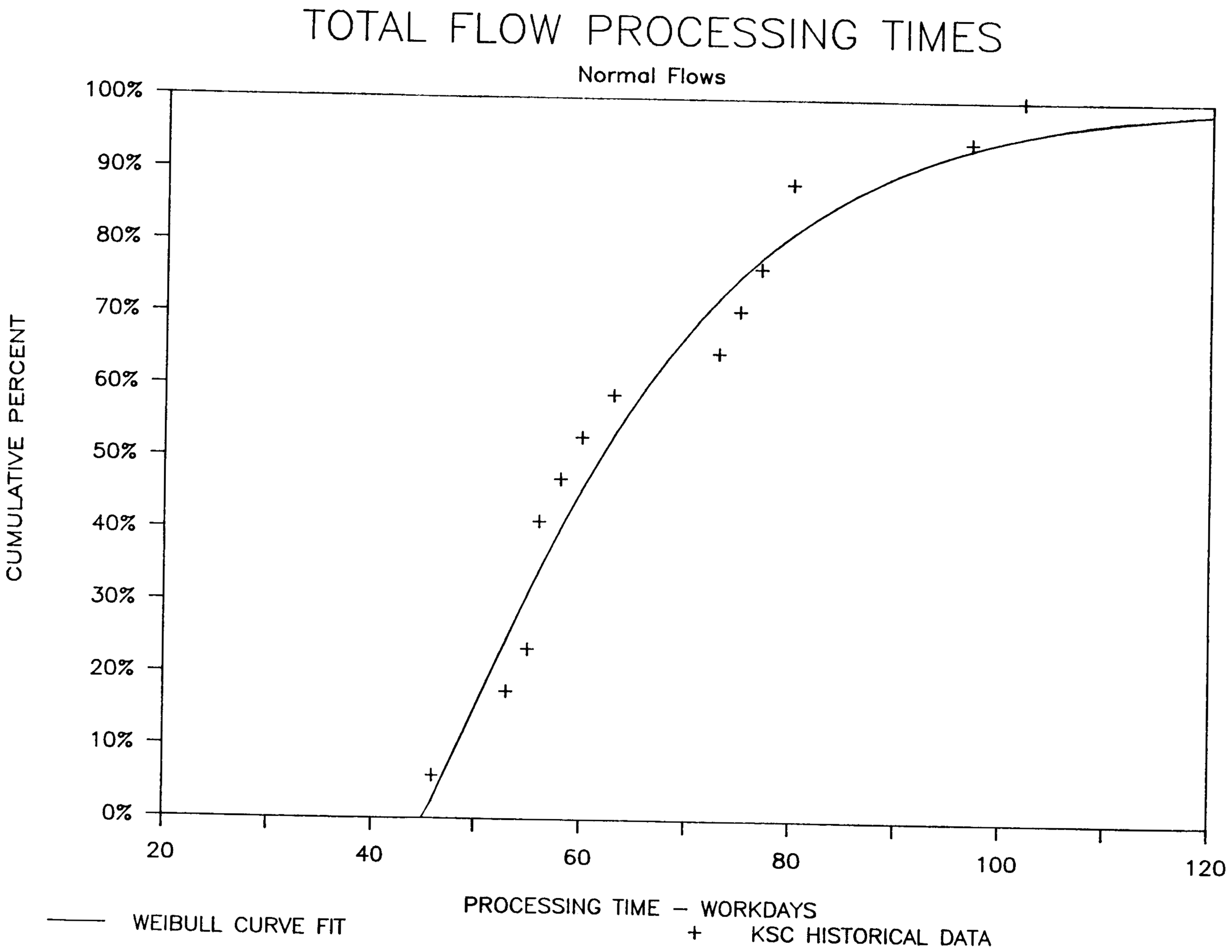

TOTAL FLOW PROCESSING TIMES
Normal Flows
CUMULATIVE PERCENT
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
20
40
60
80
100
120
PROCESSING TIME – WORKDAYS
WEIBULL CURVE FIT
+ KSC HISTORICAL DATA

Figure 4

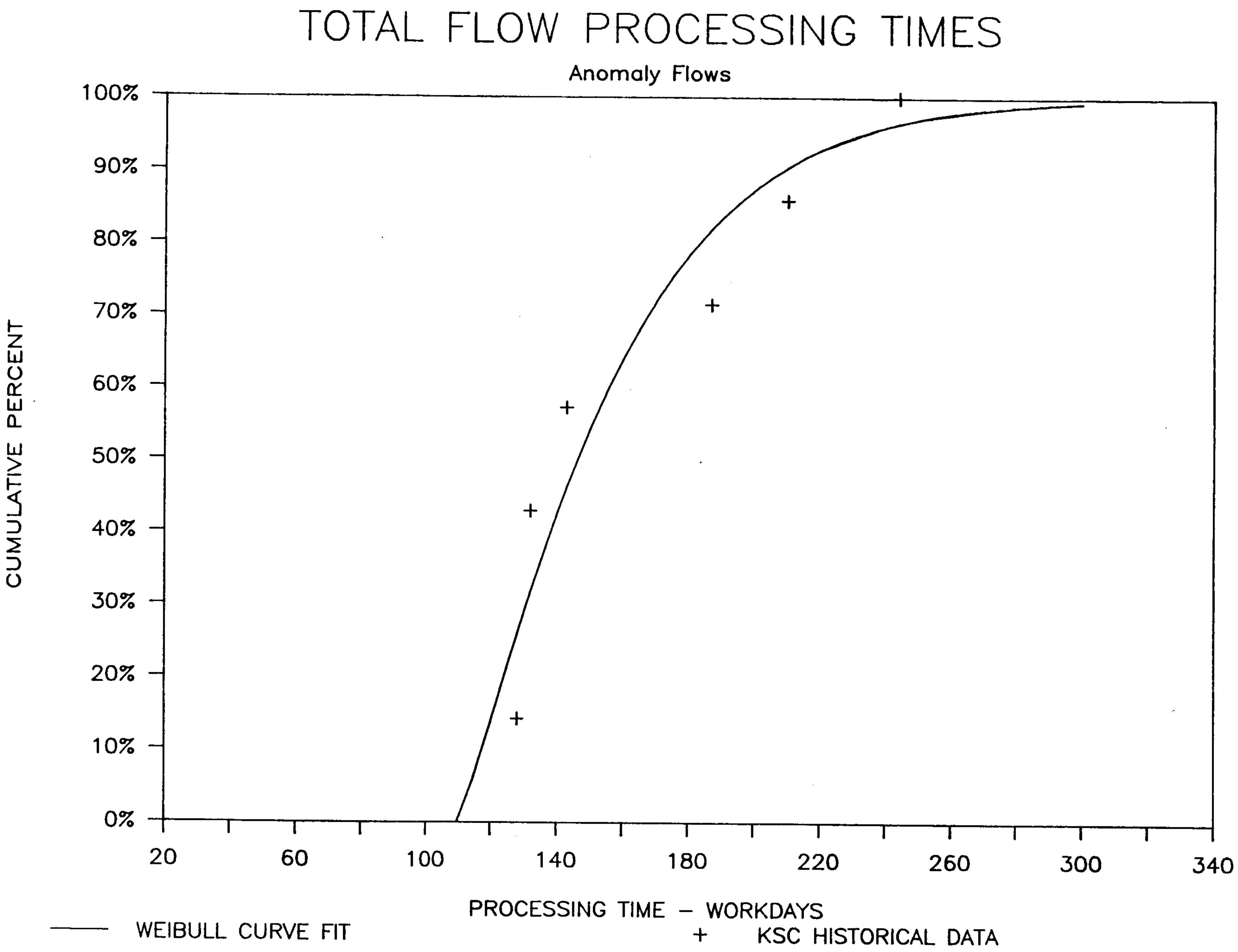

TOTAL FLOW PROCESSING TIMES
Anomaly Flows
CUMULATIVE PERCENT
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
20
60
100
140
180
220
260
300
340
PROCESSING TIME – WORKDAYS
WEIBULL CURVE FIT
+ KSC HISTORICAL DATA

Figure 5

$$F(x;\ \theta,\ \beta,\ \delta) = 1 - \exp-[(x-\delta)/(\theta-\delta)]^{\beta}\ ,\qquad x >= \delta.$$

Now let $F(x;\ \theta,\ \beta,\ \delta) = U$, a uniformly distributed random variate. Substituting and solving for x we obtain:

$$x = [(\theta - \delta)(\ln(1 - U))^{1/\beta}] + \delta.$$

The parameters θ, β, and δ are known from before and the random variate U is input to generate x, a processing time along the Weibull distribution described by θ, β, and δ. The approach taken to simulate the Shuttle processing flow is as follows:

Using the previously derived parameters for the Weibull distributions, 50 Normal and 50 Anomaly shuttle processing flows are randomly generated. One set of such randomly generated flows is shown in Table 5. In order to calculate a total processing time to produce 50 shuttle processing flows, these flows must be summed with attention given to the expected proportion of Normal vs Anomaly flows.

As stated in Assumption 3, we may expect one-fourth of the future flights to be Anomalies. Thus, the sum of the 50 generated processing times is taken to be 3/4 of the sum of the 50 Normal flows plus 1/4 of the sum of the 50 Anomaly flows (again, see Table 5).

The above is repeated 50 times to generate a total of 50 sets of 50 processing flows. The number of flows and sets of flows was chose to be 50 for two reasons. First, if fewer than 30 sets of flows are used, the confidence intervals of the resulting distribution for the mean processing time must be calculated using the Students-t

Table 5
Simulation of Shuttle Processing Flows Using Weibull Distributions

Simulation of Fifty Normal Flows

WEIBULL PARAMETERS

theta= 67.79
beta= 1.2
delta= 45

Simulation of Fifty Anomaly Flows

WEIBULL PARAMETERS

theta= 159.52
beta= 1.2
delta= 110

	Normal Flows		Anomaly Flows
1	47.8	1	128.0
2	70.5	2	115.3
3	58.1	3	176.0
4	57.4	4	115.4
5	76.9	5	151.9
6	55.1	6	158.1
7	59.2	7	111.5
8	94.4	8	119.1
9	79.6	9	187.1
10	100.3	10	133.8
11	51.5	11	140.0
12	56.1	12	161.7
13	49.5	13	135.5
14	76.5	14	162.9
15	74.2	15	120.0
16	60.8	16	212.0
17	63.7	17	153.6
18	76.1	18	174.2
19	60.8	19	203.3
20	56.6	20	167.8
21	46.1	21	173.9
22	52.7	22	190.5
23	82.7	23	124.4
24	87.9	24	213.4
25	50.6	25	125.3
26	106.8	26	141.1
27	122.3	27	113.1
28	91.2	28	189.8
29	69.7	29	204.7
30	84.0	30	132.2
31	64.1	31	153.9
32	119.6	32	131.1
33	82.6	33	255.8
34	51.9	34	130.8
35	61.4	35	146.6
36	69.5	36	165.8
37	53.2	37	119.2
38	64.2	38	199.8
39	97.1	39	141.4
40	54.7	40	158.3
41	58.1	41	188.6
42	112.1	42	159.4
43	50.8	43	186.7
44	61.0	44	158.4
45	58.5	45	119.1
46	47.4	46	147.7
47	70.1	47	251.3
48	112.9	48	143.7
49	85.4	49	163.9
50	59.5	50	193.8
sum=	3553.3	sum=	7950.9

One Set of Fifty Processing Flows

three quarters normal	2665.0
one quarter anomaly	1987.7
SUM	4652.7

distribution. This would yield a confidence interval unacceptably large for this application. Using more than 30 samples (flows) allows the use of the Standard Normal distribution to calculate confidence intervals. As desired, the confidence interval width decreases as the number of samples (flows) increases.

However, these simulations were accomplished on a microcomputer using the LOTUS 1-2-3 spreadsheet and graphics programs. The simulation rapidly gets too unwieldy and demanding of computer time if a very large number of samples is used. Because 50 flows and sets of flows yields a satisfactory confidence interval width (as will be shown below) the author settled upon this number as a matter of practicality. The 50 sets of 50 randomly generated processing flows are shown in Table 6.

II.D. Determination of Confidence Intervals for Mean Processing Flow Time.

By the Central Limit Theorem, the mean processing times for the 50 sets of flows are taken to be normally distributed. Thus, confidence intervals for the true mean, μ, of the time to process 50 flights may be calculated. The method used is that shown by Walpole and Meyers [8] for the case where the distribution's standard deviation, σ, is unknown, but the sample standard deviation, s, may be used as an approximation. The confidence interval is calculated by:

$$\bar{x} - Z_{\alpha/2}(s/\sqrt{n}) < \mu < \bar{x} + Z_{\alpha/2}(s/\sqrt{n})$$

Table 6

Fifty Sets of Fifty Flows

Normal distribution		Z(alpha/2)	
Mean	4439.9	99%	2.575
Variance	10814.5	95%	1.960
SDev	104.0	90%	1.645

Confidence Intervals for Mean Time to Process 50 Flights

99%	4402.1	<=Xbar<=	4477.8	workdays
95%	4411.1	<=Xbar<=	4468.8	
90%	4415.7	<=Xbar<=	4464.1	

Fifty Sets of Fifty Processing Flows

	X	X^2
1	4219.6	17805203
2	4252.1	18080629
3	4278.5	18305635
4	4299.1	18482601
5	4299.4	18485039
6	4314.5	18615208
7	4318.3	18647698
8	4319.5	18658109
9	4320.9	18669874
10	4341.9	18851996
11	4354.3	18959615
12	4362.0	19027092
13	4364.3	19047363
14	4371.6	19110746
15	4389.1	19264094
16	4391.5	19285102
17	4391.5	19285367
18	4392.1	19290140
19	4394.2	19308795
20	4422.9	19561763
21	4423.8	19569800
22	4426.4	19593218
23	4431.0	19633736
24	4433.2	19652961
25	4434.8	19667821
26	4438.6	19700742
27	4438.9	19703562
28	4440.1	19714164
29	4447.0	19775644
30	4449.5	19797756
31	4472.6	20004276
32	4472.7	20004892
33	4479.6	20066533
34	4483.3	20100255
35	4488.5	20146757
36	4489.5	20155943
37	4497.3	20225434
38	4507.0	20312947
39	4517.5	20408068
40	4530.1	20521591
41	4532.1	20539789
42	4534.6	20562401
43	4561.5	20807144
44	4578.8	20965189
45	4580.3	20979330
46	4580.4	20979714
47	4595.3	21116354
48	4617.0	21316660
49	4643.6	21563284
50	4674.3	21849063
SUM	221996.3	9.9E+08

where $(1 - \alpha)100\%$ is the desired confidence level, $Z_{\alpha/2}$ is the value of the standard normal distribution with an area of $\alpha/2$ to the right, $\bar{x}$ is the mean of our size n sample, and the sample standard deviation

$$s = \sqrt{[(\sum x^2-n(\sum x)^2) / (n(n-1))]}.$$

The results of these calculations are given in Table 6 for levels of confidence of 90, 95, and 99 percent. Having calculated the confidence interval for the mean time to process 50 flights, μ, this data may be used to calculate the confidence interval for the NSTS flight rate.

II.E. Results of Flight Rate Calculations Using Statistical Distributions.

Thus far we have only accounted for the time to process the space shuttle hardware processing time. We must also allow for time of flight and transportation time for the orbiter after landing. An additional allowance of time is added to the above flow processing time confidence interval limits to account for 50 seven day flights, and 25 five day returns from an Edwards Air Force Base landing (NASA´s program plan calls for half of the future shuttle flights to land at Edwards AFB and the other half at KSC). The flight rate (FR) is now calculated by:

FR = #orbiters x #workdays/yr x 50 flights/#days required.

The results of these calculations are given in Table 7 for a four orbiter fleet, at confidence levels of 90, 95, and 99 percent, and for various numbers of workdays per week. As shown in Table 7, the NSTS flight rate estimates

Table 7

Calculation of NSTS Flight Rate from Table 6 Data

Additional Time Required for Flight
and Shuttle Orbiter Transportation

Flight Duration (7*50)	350
Transport to KSC (5*25)	125
Flight and Transport Time	475 workdays

4 Orbiter Fleet Mean Flight Rate

workdays/yr				
365	14.97	>=FRate>=	14.74	99% confidence
312	12.79	>=FRate>=	12.60	
260	10.66	>=FRate>=	10.50	
250	10.25	>=FRate>=	10.10	

workdays/yr				
365	14.94	>=FRate>=	14.77	95% confidence
312	12.77	>=FRate>=	12.62	
260	10.64	>=FRate>=	10.52	
250	10.23	>=FRate>=	10.11	

workdays/yr				
365	14.93	>=FRate>=	14.78	90% confidence
312	12.76	>=FRate>=	12.63	
260	10.63	>=FRate>=	10.53	
250	10.22	>=FRate>=	10.12	

range from approximately 10 flights per year to approximately 15 flights per year, depending on the number of workdays in a year.

III. Data Analysis Using Learning Curves

III.A Evaluation of Processing Time Learning Curves.

When displayed graphically in chronological order, the data for the Total Flow (the sum of the OPF, VAB, and Pad facility flow times) appear to display a trend toward decreased processing time as flight experience increases. This gives rise to the supposition that the flow processing times are not a purely random process. To test this a learning curve is fit to the KSC facility data.

The learning curve expression is given by Chase and Aquilano [9] as:

$Y_x = K \cdot X^b$, where $b = \text{Log}_{10}(R)/\text{Log}_{10}(2)$

R = the learning rate $0 < R <= 1$

K = processing time for the first Flow

Y_x = processing time for the x´th Flow

This expression is fitted to the Total Flow data using the Kolmogorov-Smirnov goodness of fit test discussed in section II.B. This is done for both the Normal and Anomaly flows.

Fitting a single learning curve to all of the normal flows yields unsatisfactory results due to the dispersion present in the data. Application of control limits to the learning curve gives no improvement. For example: more than five percent of the cumulative experience falls outside of the calculated 95% control limits (Fig 6).

Better results may be had by bounding the data with optimistic and pessimistic learning curves. The optimistic

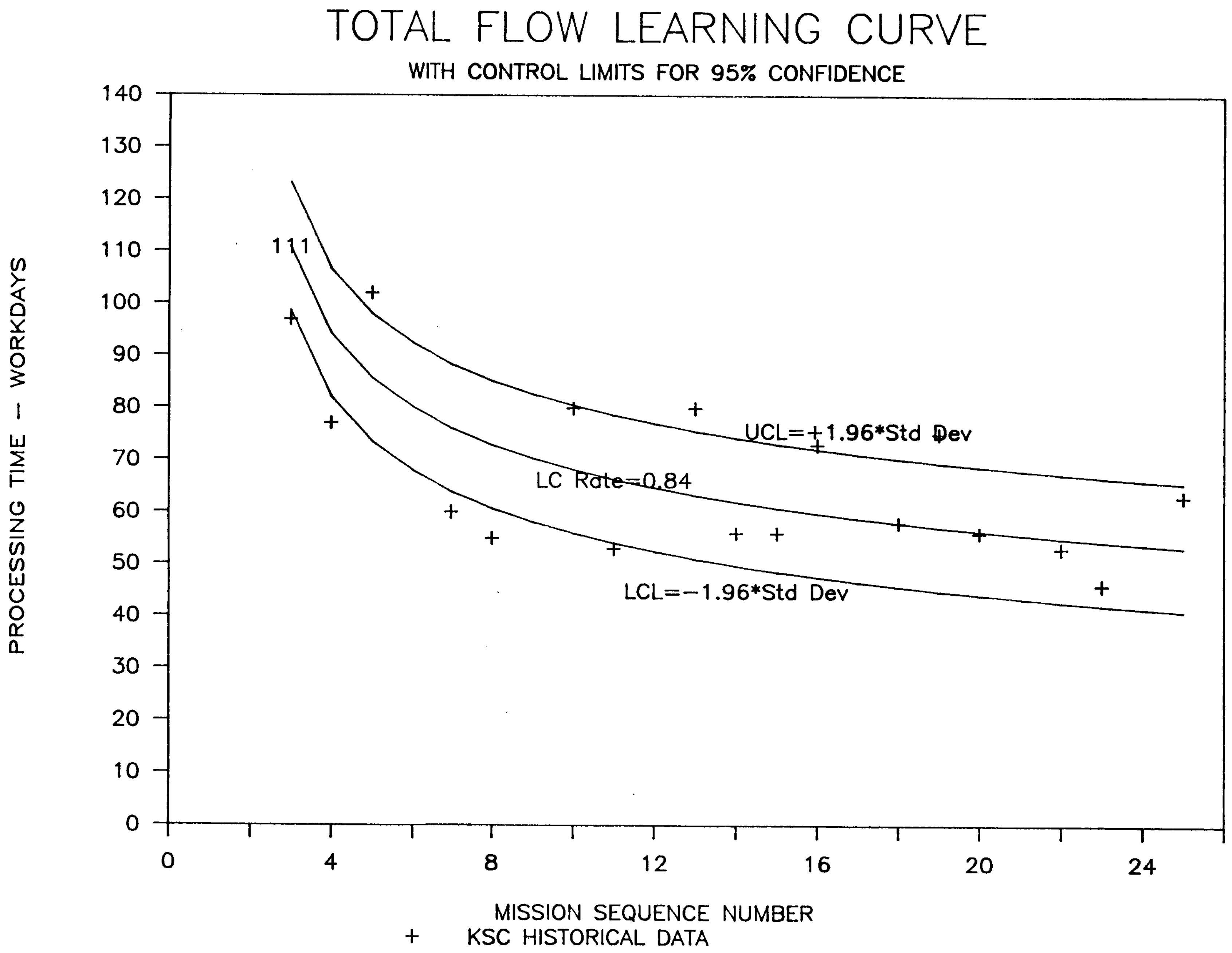

TOTAL FLOW LEARNING CURVE
WITH CONTROL LIMITS FOR 95% CONFIDENCE
PROCESSING TIME — WORKDAYS
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
111
UCL=+1.96*Std Dev
LC Rate=0.84
LCL=-1.96*Std Dev
0
4
8
12
16
20
24
MISSION SEQUENCE NUMBER
+ KSC HISTORICAL DATA

Figure 6

learning curve is the best fitting learning curve calculated for the outlying data on the low extreme of the experience time range. The pessimistic learning curve is the best fitting learning curve calculated for the outlying data on the high extreme of the experience time range.

The Anomaly flow learning curves use flight number two as an initial point. The Normal flow learning curves use flight number three as an initial point (flight number three is the first flight considered "normal"). Processing time for the initial points is allowed to be variable to achieve a best fit of the learning curves to the data. Tables 8 and 9 summarize the results of the successful learning curve fits to bound the flow processing time experience ranges with optimistic and pessimistic learning curves. Those tables also indicate the data points used to fit the optimistic and pessimistic learning curves. Figures 7 and 8 show these results graphically for the Normal and Anomaly flows, respectively.

III.B Estimation of Flow Processing Times for Future Flights Using Learning Curve Results.

The learning curves determined above are used to estimate the NSTS flight rate in much the same manner as the Weibull distributions in section II.C. But, since the processing times estimated by the learning curves are a function of both the learning rate and the flow number, and are not randomly generated, a slightly different technique must be used.

Table 8

TOTAL FLOW LEARNING CURVE
"Normal Flows"

			OPTIMISTIC LEARNING CURVE			PESSIMISTIC LEARNING CURVE		
Mission Seq #	LrnCurve Seq #	Total Flow Time	Data Pt Used	Rate 0.83	Abs Diff Tot-Calc	Data Pt Used	Rate 0.88	Abs Diff Tot-Calc
1								
2								
3	1	97	*	95	2.000		120	
4	2	77	*	79	1.850		106	
5	3	102		71		*	98	4.009
6	4			65			93	
7	5	60	*	62	1.635		89	
8	6	55	*	59	3.687		86	
9	7			56			84	
10	8	80		54		*	82	1.777
11	9	53	*	53	0.373		80	
12	10			51			78	
13	11	80		50		*	77	2.888
14	12	56		49			76	
15	13	56		48			75	
16	14	73		47		*	74	0.758
17	15			46			73	
18	16	58		45			72	
19	17	75		44		*	71	3.837
20	18	56		44			70	
21	19			43			70	
22	20	53		42			69	
23	21	46	*	42	4.093		68	
24	22			41			68	
25	23	63		41		*	67	4.305
26	24			40			67	
28	26			40			66	
30	28			39			65	
32	30			38			64	
34	32			37			63	
36	34			37			63	
38	36			36			62	
40	38			36			61	

	Max Absolute Difference	4.093	4.305
A:	Max abs diff normalized by calculated flow time for Learning Curve Sequence #1.	0.043	0.036

Table 8, concluded.

Kolmogorov-Smirnov Goodness-of-Fit Test: Ho; the sample comes from a process whose learning curve is described by the rate and initial processing time described above.

B: Max Acceptable Absolute Difference for n=6, and Significance Level = 0.20.	0.265	0.265

Since A < B, for both the Optimistic and Pessimistic Learning Curves, we cannot reject the Ho for either case.

Table 9

TOTAL FLOW LEARNING CURVE
"Anomaly Flows"

			Optimistic Learning Curve			Pessimistic Learning Curve		
Mission Seq #	LrnCurve Seq #	Total Flow Time	Data Pt Used	Rate 0.92	Abs Diff Tot-Calc	Data Pt Used	Rate 0.95	Abs Diff Tot-Calc
1								
2	1	187	*	177	10.000		263	
3	2			163			250	
4	3			155			242	
5	4			150			237	
6	5	244		146		*	233	10.530
7	6			143			230	
8	7			140			228	
9	8	128	*	138	9.828		225	
10	9			136			224	
11	10			134			222	
12	11	210		133		*	220	10.238
13	12			131			219	
14	13			130			218	
15	14			129			216	
16	15			128			215	
17	16	132	*	127	5.198		214	
18	17			126			213	
19	18			125			212	
20	19			124			212	
21	20	132	*	123	8.557		211	
22	21			123			210	
23	22			122			209	
24	23	143		121			209	
25	24			121			208	
26	25			120			207	
28	27			119			206	
30	29			118			205	
32	31			117			204	
34	33			116			203	
36	35			115			202	
38	37			115			201	
40	39			114			201	
Max Absolute Difference					10.000			10.530
A: Max abs diff normalized by calculated flow time for Learning Curve Sequence #1.					0.056			0.040

Table 9, concluded

Kolmogorov-Smirnov Goodness-of-Fit Test: Ho; the sample comes from a process whose learning curve is described by the rate and initial processing time described above.

B: Max Acceptable Absolute Difference for n=4, and Significance Level = 0.20.	0.300	>0.300 for n=2, and Significance Level = 0.20.

Since A < B, for both the Optimistic and Pessimistic Learning Curves, we cannot reject the Ho for either case.

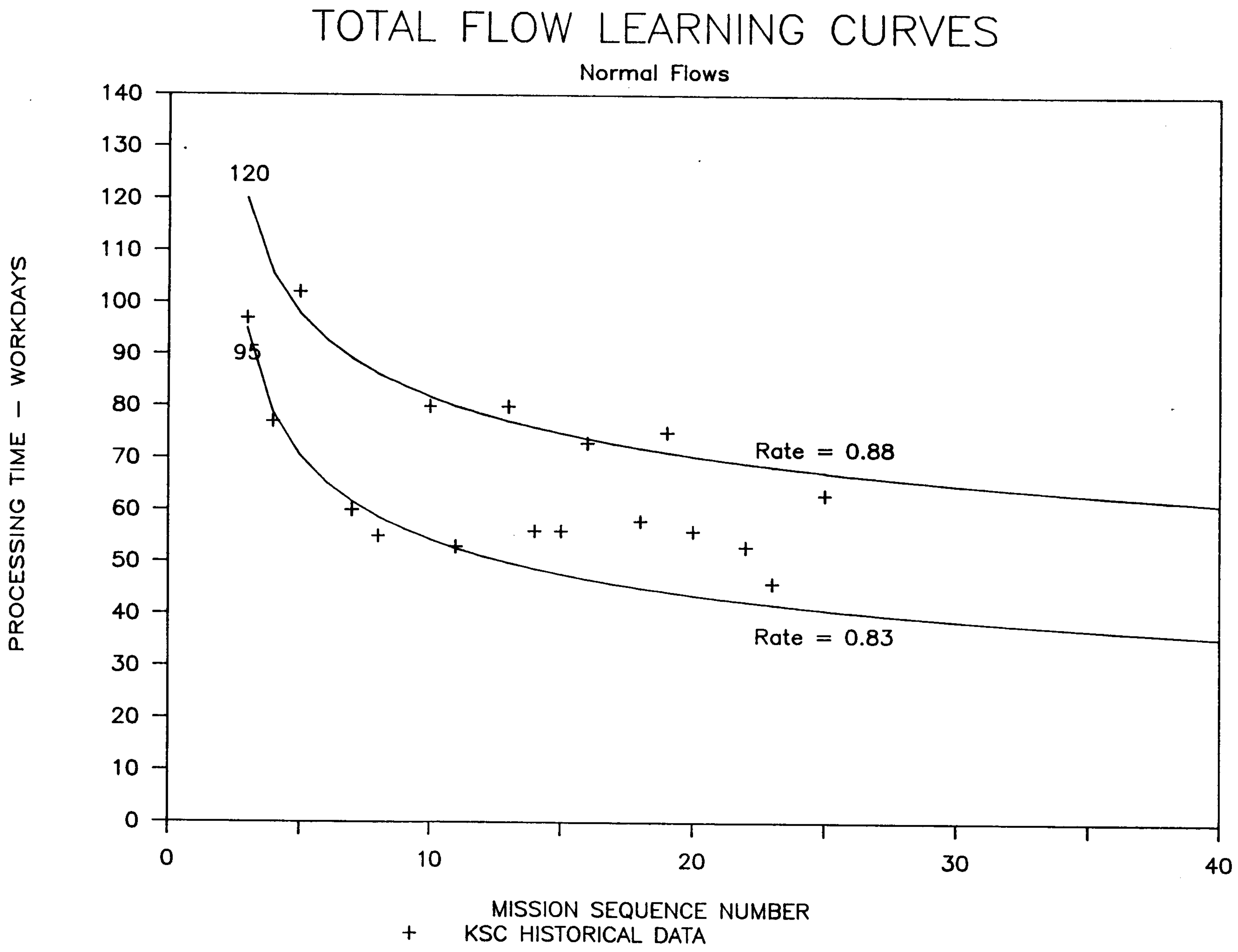

TOTAL FLOW LEARNING CURVES
Normal Flows
PROCESSING TIME — WORKDAYS
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
120
95
Rate = 0.88
Rate = 0.83
0
10
20
30
40
MISSION SEQUENCE NUMBER
+ KSC HISTORICAL DATA

Figure 7

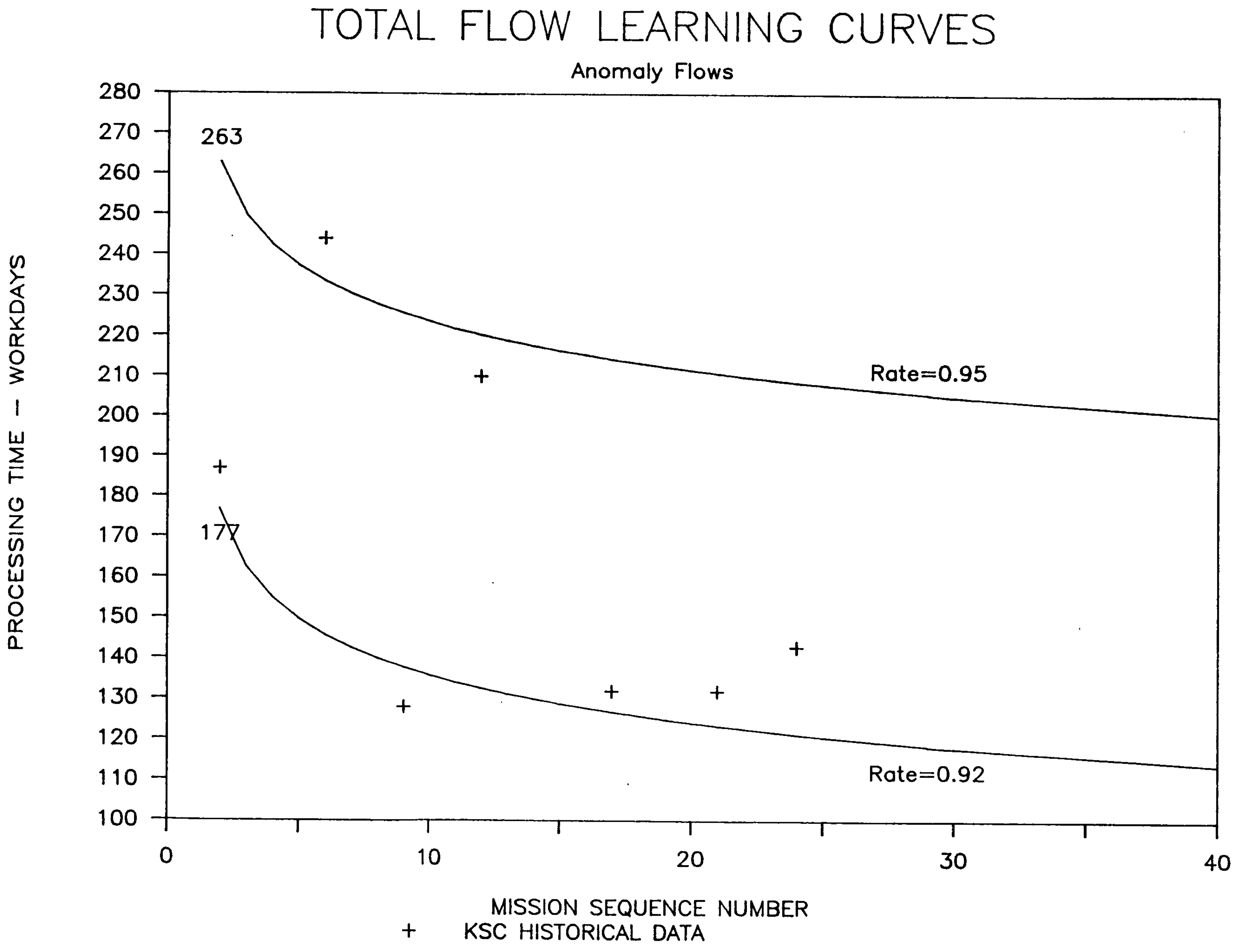

TOTAL FLOW LEARNING CURVES
Anomaly Flows
PROCESSING TIME — WORKDAYS
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
263
177
Rate=0.95
Rate=0.92
0
10
20
30
40
MISSION SEQUENCE NUMBER
+ KSC HISTORICAL DATA

Figure 8

For the analysis hypothetical flights 41 through 60 have been examined. These particular missions are of interest because, had the Challenger accident on mission sequence number 25 not occurred, the flight schedule would likely be in this range at the present time. Also, flights 41-60 are sufficiently far along on the learning curves that the change in processing time with increasing flight number approximates a straight line. Thus 20 flows are sufficient to determine the mean flight rate and we need not bother simulating 50 slows as in Section II.

Twenty processing flow times were generated for both the Normal and Anomaly flows, and are given in Table 10. As for the case described in section II.C, the sum of the 20 flow times is taken to be 3/4 of the sum of the 20 normal flow times plus 1/4 of the sum of the 20 anomaly flow times. To this was added 7 x 20 flight days and 5 x 10 orbiter transportation days to return from Edwards AFB (again, half the Shuttle landings are expected to occur at Edwards AFB, requiring 5 days transportation time to KSC).

III.C. Results of Learning Curve Flight Rate Calculations.

The average flight rate (FR) is calculated by:

FR = #orbiters x #workdays/yr x 20 flights/#days required.

Rather than calculate confidence intervals as was done previously, we are only able to provide optimistic and pessimistic flight rates. The results of the optimistic and pessimistic learning curve flight rate calculations are shown in Table 10. As shown, the mean flight rate for the hypothetical flights 41-60 varies from an optimistic 22.7 at 365 workdays per year to a pessimistic 9.7 flights per year at 250 workdays per year.

Table 10

Calculation of NSTS Flight Rate Using Results of Learning Curve Analysis

	Generated Flow Times			
Mission	Optimistic		Pessimistic	
Seq #	Normal	Anomaly	Normal	Anomaly
41	35	114	61	200
42	35	113	61	200
43	35	113	60	199
44	35	113	60	199
45	35	112	60	199
46	34	112	60	198
47	34	112	59	198
48	34	111	59	198
49	34	111	59	197
50	34	111	59	197
51	33	111	59	197
52	33	110	58	197
53	33	110	58	196
54	33	110	58	196
55	33	110	58	196
56	33	109	58	196
57	32	109	57	195
58	32	109	57	195
59	32	109	57	195
60	32	108	57	194
SUM OF FLOW TIMES	671	2216	1175	3943
x	0.75	0.25	0.75	0.25
	503	554	881	986

	Optimistic	Pessimistic
Normal Flows	503	881
Anomaly Flows	554	986
Flight Duration (7x20)	140	140
Orb transport to KSC (5x10)	50	50
Total Workdays Required	1247	2057

4 Orbiter Fleet Flight Rate for various work weeks

Work days/week	Days/Yr	Flight Rate Optimistic	Flight Rate Pessimistic
7 days/week	365	23.4	14.2
6 days/week	312	20.0	12.1
5 days/week	260	16.7	10.1
5/week - 10 holidays	250	16.0	9.7

IV. Conclusions

Conclusion 1: Because the results of the analyses in sections II and III are significantly different, the methods of analysis appear to be sensitive to the circumstances of their application. The flight rate analysis using probability distributions does not account for any Learning Curve effects. For an application such as the Space Shuttle processing flows, where the execution times can be quite large at first, Learning Curve effects may produce a significant change in system capacity over the long term. As shown in Section III, some Learning Curve effects are present in the past Shuttle processing experience data. Therefore, we must conclude that the application of a probabilistic flight rate analysis in these circumstances may yield pessimistic results compared to the actual future capacity of the system.

Conclusion 2: Based on the Caveats in section I.D and the results presented in Sections II and III, above, it appears likely that the NSTS program will experience difficulty in achieving the currently planned maximum sustained flight rate of 14 flights per year. Even though the results presented in section III show a flight rate capacity of up to about 23 flights per year, this was based upon a maximum effort work schedule requiring 365 workdays per year. Certainly this work schedule cannot be maintained for an extended period of time.

Because of the large amount of scatter in the data, the learning curves for the Shuttle processing flow data were difficult to define. The difference between the optimistic and pessimistic flight rate estimates is about one-third of the optimistic estimate. This is a large amount of uncertainty and does not inspire confidence.

Additionally, all of the caveats and assumptions presented in section I.D were such as to guarantee optimistic results from this analysis. Yet, to meet these estimates the Normal and Anomaly flow experience would both have to always progress at the most optimistic learning rates displayed. Therefore, we conclude that the analysis results show only marginal capability to meet the planned maximum sustained flight rate of 14 flights per year, and only if significant learning curve progress can be sustained and/or work schedules allowing few holidays and down weekends are used over long periods of time.

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CHAPTER V

CONTRACTUAL EFFORT

V. CONTRACTUAL EFFORT

The research work undertaken by our team has been generally on target with respect to the estimated timeline for the proposed study (Figure 5.1) given in the Statement of Work. In order to further the research into the methods for transition management in high-technology companies, work is in progress to schedule more interviews in the next quarter. Also, the work on scheduling jobs in a flow shop with multiple processors has also been extended. Additionally, a heuristic programming study to observe the performance of different priority or dispatch rules for various criteria was performed. Efforts are being made to identify scheduling criteria and solution methodologies for the space shuttle scheduling problem. Finally, the progress on the adaptation of industrial and theoretical techniques for consideration of the NSTS is also satisfactory. Moreover, ther analysis tools and techniques are being investigated to provide input into the successful implementation of NSTS's transition management program.

We anticipate that the research work will continue to progress smoothly in the upcoming quarter, with all tasks being on schedule. As we enter the fourth quarter of the research grant work, the emphasis is on continuing the analysis and development of concepts and models that can be adapted to NASA's needs.

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   0                                                           12
   !                                                           !
   !    1    2    3    4    5    6    7    8    9    10   11   !
   !----!----!----!----!----!----!----!----!----!----!----!----!
   !                                                           !
START-UP      QUARTERLY      QUARTERLY        QUARTERLY      FINAL
               REPORT         REPORT           REPORT        REPORT


   !---------- INDUSTRIAL INVESTIGATION --------!

   !---- STUDY OF FLOW SHOP SCHEDULING ----!
         FOR SPACE SHUTTLE APPLICATION

        !------------ LITERATURE SEARCHES -----------!

                            !-- ANALYSIS OF LIT. SEARCH --!
                                 AND INTERVIEW PROCESS

                                 !-ADAPTATION OF ANALYSIS-!
                                    TO THE NSTS PROGRAM

   !------ ADAPTATION OF INDUSTRIAL AND THEORETICAL ------!
             TECHNIQUES FOR CONSIDERATION OF NSTS

                                                          !----!
                                                          FINAL
                                                          REPORT
```

FIGURE 5.1. ESTIMATED TIMELINE FOR THE PROPOSED STUDY