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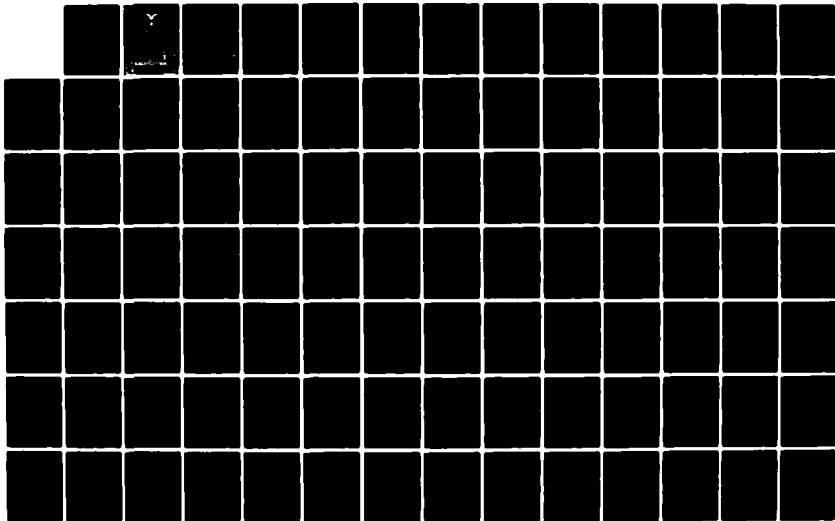
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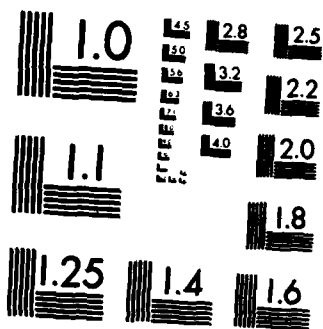
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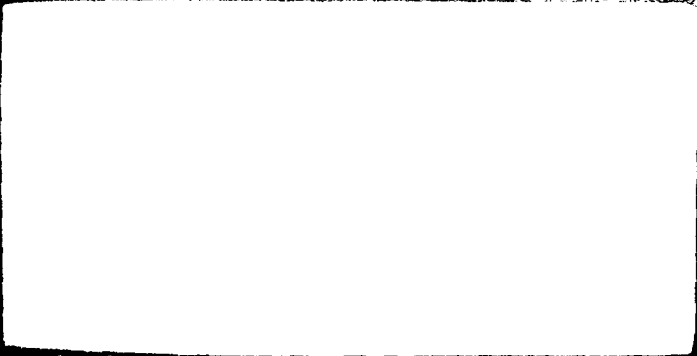
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AN ANALYSIS OF THE SPACE TRANSPORTATION
SYSTEM LAUNCH RATE CAPABILITY UTILIZING
Q-GERT SIMULATION TECHNIQUES

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AN ANALYSIS OF THE SPACE TRANSPORTATION SYSTEM
LAUNCH RATE CAPABILITY
UTILIZING Q-GERT SIMULATION TECHNIQUES

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Masters of Science

by

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December 1982

Preface

As students in the Air Force Institute of Technology's Graduate Program in Space Operations, we are quite interested in the progress of the Space Transportation System. This system will be the primary means of launching DoD payloads into earth orbit. In fact, DoD payloads will fly on up to half of all flights after 1988. Therefore, any short falls the system may have in launch rate capability will have a big impact on DoD. A review of the trade literature indicated that the system has already reached the point of saturation and that NASA has been unable to fund the hardware procurement and facility construction needed to increase the system launch rate to a level sufficient to meet user needs. Therefore, additional operational funding will have to be applied to the system in the near future. As this funding is bound to be limited, it must be wisely spent on those portions of the system which will contribute greatest to increasing the launch rate. The purpose of our thesis was to develop a launch rate enhancement plan which will present the proper sequence in which flight hardware and facilities should be added. This plan also had to provide accurate estimates of STS launch rate capability given various configurations of hardware and facilities. Therefore, the problem was to develop a method which would accurately predict STS launch rate capability and identify the bottlenecks in the system. Two such methods were devised. The analytic method was originally intended for use in validating the simulation results, but it was found to be accurate enough to be useful by itself. Of course, if the most accurate results are desired, the simulation method is the one to use. The launch enhancement plan developed from the two models is presented

in Chapter VI. As expected, the capacity of the system is less than that anticipated by the current flight schedule. The plan can therefore be used as a guide to determine what facilities and hardware to add to meet the scheduled flights. In addition, it provides planners with a tool to judge the financial viability of meeting various launch rates.

We would like to thank our Advisor, Major Joseph Coleman of AFIT, for his guidance in preparing this work. We would also like to express our sincere thanks to Mr. Herbert Fogarty of Rockwell International, and Mr. Porter Bridwell and Mr. Vince Caruso of George C. Marshall Spaceflight Center for their kind help in providing the data needed to prepare this report. Finally, we would like to thank our wives and kids for putting up with us during the preparation of this thesis.

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List of Abbreviations

ET External Tank
KSC Kennedy Space Center
OMCF Orbiter Maintenance and Checkout Facility (Vandenberg AFB)
OPF Orbiter Processing Facility (Kennedy Space Center)
PSF Processing and Storage Facility (SRBs)
SRM Solid Rocket Motor
SRB Solid Rocket Booster
STAR Shuttle Turnaround Analysis Report (Kennedy Space Center)
VAFB Vandenberg AFB
VSTAR Vandenberg AFB Shuttle Turnaround Analysis Report

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Abstract

The Space Transportation System (STS) is being developed by NASA for NASA, DoD, and commercial use. National Space Policy dictates that the STS become NASA's and DoD's primary means for launching payloads into earth orbit. Unfortunately, the current flight manifest saturates STS launch rate capability. Therefore, additional operational funding will be required to increase it. This funding must be applied to those portions of the system which contribute greatest to increasing the system launch rate. This study presents two methods for determining the system launch rate, identifying the bottlenecks, and developing a launch enhancement plan. The analytic method is fairly easily and quickly done, using the data provided in the NASA Shuttle Turnaround Analysis Report, while the Q-GERT simulation method gives more accurate estimates of launch rate capability. Plans are presented to show the facility configurations and flight hardware levels required to produce various launch rates at Kennedy Space Center. The capacity of VAFB was determined, but no launch enhancement plan was developed for it since an increase in its launch rate would require the obvious duplication of most of its facilities. The methods presented can be used on the data provided in future STARs.

AN ANALYSIS OF THE SPACE TRANSPORTATION SYSTEM LAUNCH
RATE CAPABILITY UTILIZING Q-GERT SIMULATION TECHNIQUES

I. Introduction

The Space Transportation System (STS) is being developed by NASA for NASA, DoD, and commercial use. This system is comprised of the Space Shuttle flight hardware, their production facilities, and the launch processing facilities at Kennedy Space Center (KSC) and Vandenberg AFB (VAFB). National Space Policy directs that the STS be the primary resource for launching payloads into orbit. It also directs DoD to assure the systems utility for national defense (Ref 1:2-3). Therefore, most DoD payloads will be launched by the STS. In fact, the current flight manifest shows that 35% of the STS flights scheduled between 1982 and 1988 will carry DoD payloads, and the percentage will rise to 50% after that (Ref 2:42). These DoD payloads will include missile warning, surveillance, communication, navigational, and meteorological satellites (Ref 2:40). In addition, technology now being developed could be integrated into space based weapon systems for national defense. Some of these systems would require STS launch due to their large size (Refs 3:15; and 4:41).

Unfortunately, currently scheduled flights already saturate STS capability, and high system development costs have prevented NASA from procuring the flight hardware and processing facilities needed to produce the launch rate required to meet user needs (Refs 5:20; and 6:16-17). Therefore, additional operational funding will be required

to increase the STS launch rate. However, tight economic conditions and the major military modernization program underway will make funding for space projects hard to obtain. That space funding which is obtained must be wisely spent to insure that critical national defense needs are met. Therefore, operational funding for STS launch rate enhancement must be spent on those portions of the system which will contribute greatest to increasing the system launch rate.

Problem and Scope

The purpose of this thesis is to develop a plan for increasing the STS launch rate capability. The problem is to develop a method which can accurately predict STS launch rate capability given various facility configurations and flight hardware levels. This method must take into account the flow of flight hardware through the launch processing facilities, and properly reflect the complex interactions among these facilities and hardware. By accurately predicting system launch rates, the method can be used to identify the bottlenecks in the STS. A plan can then be developed to incrementally add capability to the bottlenecks in order to increase the system launch rate.

Increases in STS capability are obtained by the addition of work shifts or by facility and hardware procurement rather than by task flow adjustment. The latter method is limited by system design and is best left to the managers of the individual work centers. No funding limits are assumed. The developed plan simply shows what work shifts and facilities have to be added, and what hardware has to be procured to meet various launch rates. It is left to NASA/DoD management to balance the costs associated with achieving a particular launch rate against the value of the payloads and budgetary constraints.

General Approach

This study uses a Q-GERT network to model the STS launch process flow. The Q-Gert approach is used because it is a computer analysis tool which permits direct computer analysis on graphically modeled systems (Ref 7:vii). The output from the Q-GERT Analysis Program is used to identify the bottleneck(s) in the STS process flow (Ref 7:52-55). Capacity is then added at the bottleneck(s) and the Analysis Program is rerun. Successive outputs are compared to determine if observed launch rate increases are statistically significant. This process is repeated until the desired STS launch rate is achieved. The results are then tabulated, showing the facilities/hardware required to achieve various launch rates.

Sequence of Presentation

The Space Transportation System is described in Chapter II. The research design provided in Chapter III shows the approach used to develop and analyze the Q-GERT model of the STS. Chapter III also provides parametric descriptions and the statistical testing techniques used. Described in Chapter IV are the steps taken to verify and validate the Q-GERT model and the computer results. An analytic approach which aided this validation effort is described in Chapter V. The procedure used to apply the Q-GERT techniques to determine the launch rate enhancement plan is covered in Chapter VI. This Chapter also includes a section on sensitivity analysis. Finally, the results are presented in Chapter VII, and some recommendations for future study in Chapter VIII.

Assumptions

This study bases its examination of the STS on the facilities and hardware which will be available by the beginning of fiscal year 1987. All of the facility upgrades and hardware procurement contained in current funding plans are scheduled to be operational by then. It is assumed that this schedule will hold. The facility upgrades include a second launch pad and a solid rocket Processing and Storage Facility (PSF) (Ref 8:68). Flight hardware procurement will bring the number of Orbiters to 4 and the External Tank (ET) production rate to its current limit of 24 per year (Refs 9:100; and 10:79). Plans exist to install the tooling required to increase the ET production rate to 55 per year, but the required funding is not being provided (Refs 10:79; and 6:16). However, the Solid Rocket Motor (SRM) production facility is capable of handling the maximum envisioned production rate (Ref 11:27).

It is assumed that no accidents occur to reduce the STS launch rate capability. Orbiter damage or loss is not considered, and accidents, such as hypergolic fuel spillage, are not allowed to interrupt the STS work flow.

Much of the data used for the model parameters is obtained from the Shuttle Turnaround Analysis Report (STAR 23) prepared by NASA (Ref 12). This report charts the progress being made to meet the ground turnaround design goal of 160 work hours. The turnaround time includes all the activities which take place between the time an Orbiter lands and is launched again. The report lists the various activities which are required to prepare a Shuttle Vehicle for launch. Allocated and assessed times are provided for each activity. The allocated times

are those necessary to meet the 160 hour design goal, while the assessed times are those expected when the Shuttle Program is fully operational. The assessed times assume that procedures and tasks have been optimized, and that personnel have achieved their maximum level of proficiency (Ref 12:2-2).

Finally, it is assumed that payloads are available when needed, and that the payload manifest for flights 5 through 63 is representative of the various types of payloads and their relative numbers (Ref 9).

Literature Review

An extensive review of technical and professional literature was accomplished. Library indices, such as the NASA Star Abstracts, were thoroughly searched for studies which examined the STS launch rate. The NASA Shuttle Turnaround Analysis Report, mentioned earlier, was found in this manner. NASA and Defense Technical Information Center (DTIC) computer literature searches revealed STS description reports and environmental impact statements. Also reviewed were periodicals such as Aviation Week & Space Technology, and journals such as Simulation (Refs 13; and 14). The only article found on the subject of STS launch rate was published in the June 1982 issue of Simulation. The article, "Analysis of Space Shuttle Ground Operations," was written by James R. Wilson, David K. Vaughan, Edward Naylor, and Robert G. Voss (Ref 15). Their report presented a method for determining the probability of meeting a given STS flight schedule. Their method also determines the dates by which various hardware components required for a particular flight must be available for launch processing activities (Ref 15:187). Their use of simulation techniques

is similar to the ones used in this study. However, their study did not directly identify the bottlenecks in the STS or list a plan for adding capacity to the system.

This thesis makes extensive use of the Q-GERT computer simulation techniques provided in A. Alan E. Pritsker's Modeling and Analysis Using Q-GERT Networks (Ref 7). The Q-GERT simulation language was developed to examine network flows in complex systems (Ref 7:vii-viii). Some of the systems it has been used to analyze are truck hauling operations, oil tanker port service facilities, and air cargo terminals (Ref 7:7,216,371, and 375).

Analytic techniques were examined for their usefulness in solving the launch rate problem. However, the discontinuous nature of the STS model's controllable variables, the lack of a solvable objective function to relate those variables to system launch rate, and the stochastic nature of the STS launch process prevented the use of linear programming techniques such as SIMPLEX and integer programming (Refs 16:165,261, and 437; and 17:475). Queueing Theory was adequate to model portions of the system, but the complexity of the system, and the probabilistic nature of its service activities, made an analytic solution computationally infeasible (Ref 16:432). Therefore, simulation techniques were used to generate representative samples of the system launch rate and to identify bottlenecks in the system (Ref 16:437).

A Network Theory approach was used on a substantially simplified model of the STS to produce estimates of the STS launch rates (Ref 18:483-505). However, the simplification process made this analytic solution less accurate than the simulation solution. Therefore, the analytic estimates were used only to compare to the simulation results in order to validate the latter.

II. STS System Description

The STS is comprised of flight hardware and the production and processing facilities which support that hardware. Flight hardware includes Space Shuttle Orbiters, External Tanks, and Solid Rocket Boosters (SRBs). Production facilities include the Thiokol plant which produces the SRBs, and the NASA Michoud facility at which Martin Marietta produces External Tanks. Launch processing facilities exist at Kennedy Space Center (KSC) and Vandenberg AFB (VAFB). Flights requiring orbital inclinations below 57 degrees are launched from KSC, while those requiring higher inclinations will be launched from VAFB (Ref 19:13). Restrictions against overland launches prevent either site from acting as a backup for the other.

Kennedy Space Center

A typical STS flight at KSC begins in the Orbiter Processing Facility (OPF). In this facility, the Orbiter is serviced, equipment from the previous flight is removed, and the payload bay is prepared for the next flight. Although Spacelab equipment is installed in this facility, free flying satellites are inserted into the Shuttle bay at the launch pad (Ref 20). Concurrently, an SRB pair is assembled. The aft skirt and rear segment for each SRB are assembled in the Processing and Storage Facility (PSF). That assembly is then moved to a High Bay in the Vehicle Assembly Building (VAB) and attached to a Mobile Launch Platform (MLP). The remaining SRB segments and the forward skirt are stacked, and an External Tank attached. After the Orbiter has been serviced, it is moved to the VAB and attached to the SRB/ET combination. Following system checkout procedures, the MLP, with the assembled

Shuttle Vehicle on top, is moved to the launch pad. After prelaunch servicing, the Shuttle is launched. The SRBs separate after use and are recovered for refurbishment. The External Tank, which stays with the Shuttle until it has nearly achieved orbit, detaches and burns up as it falls to Earth. The Orbiter then enters orbit, accomplishes its mission, and return to Earth. It receives post-landing servicing at the landing field, and is then towed to the OPF to begin the process anew. The recovered SRBs are washed and disassembled, the SRB motor segments are shipped to Thiokol for recasting, and the reuseable components are refurbished at KSC.

The OPF has two bays, which permits the simultaneous servicing of two Orbiters. The PSF can process one flight set of SRBs at a time, and can store components for two other sets. The VAB has four High Bays. Two of these are configured for Shuttle Vehicle assembly, while the other two contain checkout (c/o) and storage cells for the External Tanks. Should it become necessary to configure a third or fourth VAB High Bay for shuttle assemble, a separate External Tank c/o and storage facility would have to be built. There are two MLPs configured for shuttle use, and a third is available for reconfiguration. Two crawlers are available to move the MLP/Shuttle Vehicle to either of the two launch pads (Ref 8). Although the current flight manifest will soon tax the capacity of these facilities, the funds needed for facility expansion are not contained in future budget plans (Ref 6:16-17).

Vandenberg AFB

Vandenberg AFB launch processing proceeds along similar lines. The site has separate facilities for Orbiter, SRB, and External Tank processing. However, these three components are assembled at the launch

pad. The VAFB OPF is capable of handling only one Orbiter at a time, and there is only one assembly/launch pad available (Ref 21).

SRB and External Tank

SRBs are shipped to both launch sites by rail, and External Tanks are shipped by barge (Ref 22:99). The maximum scheduled production rate for both are 24 units per year, and their production facilities are designed for future expansion to 40 units per year (Refs 23; and 24). Production greater than the latter rate would require a more extensive implacement of tooling and equipment (Refs 10:79; and 22:97).

Figures 1 and 2 show the launch process flow for KSC and VAFB.

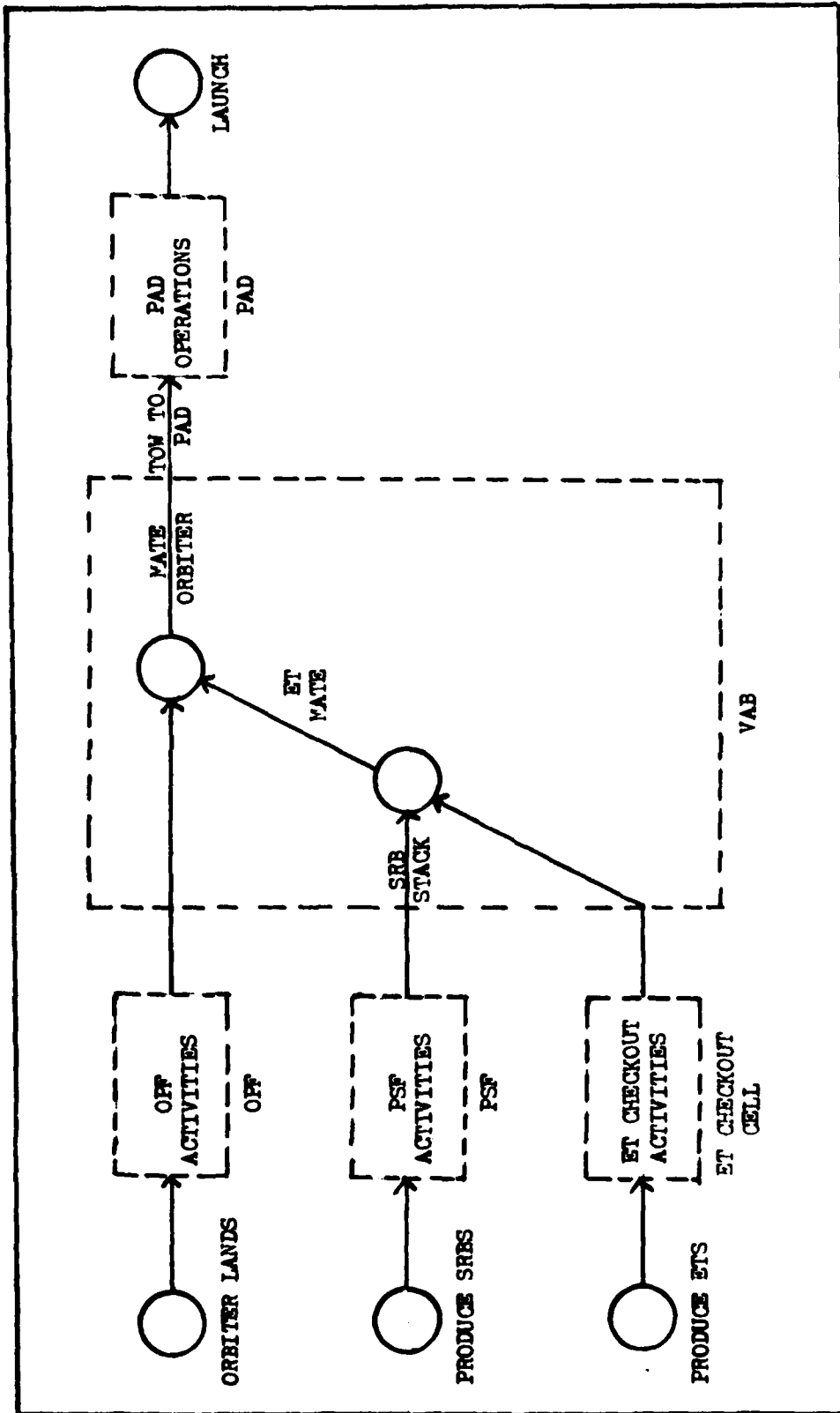


Fig. 1. KSC STS Flow

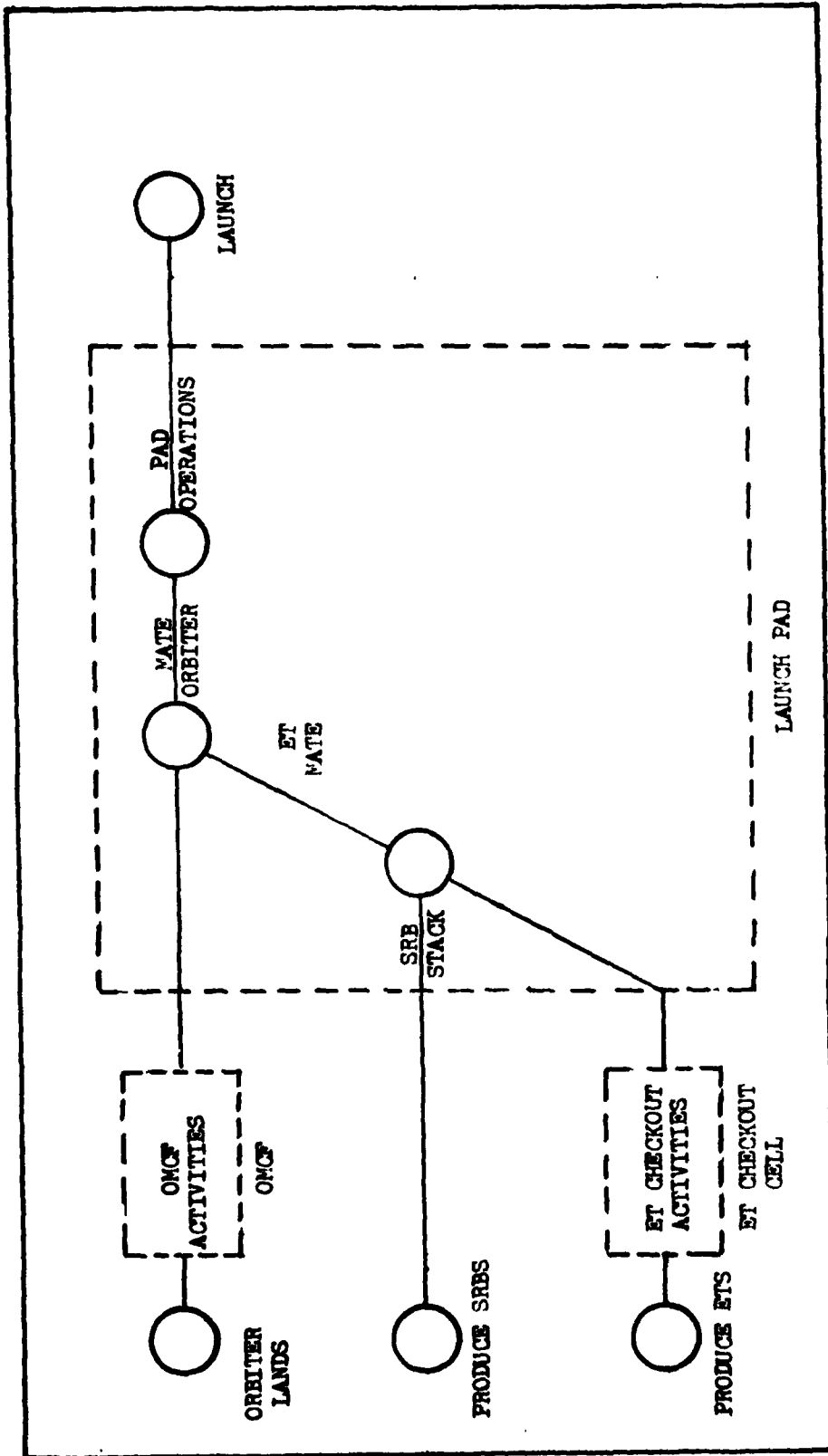


Fig. 2. VAFB STS Flow

III. Research Design

The primary purpose of this project, as stated in previous chapters, is to determine the launch rate capabilities of the STS under various configurations and to determine what facilities to add to the system in order to increase launch rate capabilities. In order to answer this question a methodology of experimentation is required. This chapter describes the process that was used to determine the experimental design utilized to answer the question mentioned above.

The first section of this chapter describes the basic research design considerations for this experiment. This design includes the response variable, the pertinent factors and their levels of interest, and design factors taken into account when designing the model. The second section presents the Q-GERT simulation technique and a brief history of some of its facilities that led us to choose this method for our analysis. The third section describes the structural and parametric models developed to depict the KSC and VAFB STS turnaround systems. The final section describes the experimental methodology used to evaluate launch rate capabilities. Also included is a description of the statistics used to test the results.

Research Design Considerations

The first step of the research design is to identify the response variable(s) desired, the dependent variables (factors) and their levels of interest, and other considerations of interest. One consideration would be to determine the type of output needed to do statistical testing on the results. This section presents each of these criteria as they pertain to this study.

Response Variable. As previously mentioned, the objective of this study is to determine the launch rate capabilities of the system under various configurations. Therefore, the primary response desired from the model needs to provide information that can be used to calculate the launch rate. Thus, the model selected must output the number of launches per year that the system is capable of producing or output something that can be converted to launches per year (such as the time between launches).

Factors. There are numerous factors which affect the launch rate capability of the system. There are, however, a limited number of factors that will both affect the launch rate and be such that they are easily altered in the actual system. The factors that were selected as the portions of the system at KSC to be varied are the following:

1. Orbiters,
2. Orbiter Processing Facility (OPF) bays,
3. Crawlers,
4. Launch Pads,
5. Mobile Launch Pads,
6. Vehicle Assembly Building (VAB) High Bays,
7. Processing and Storage Facility (PSF),
8. Solid Rocket Booster (SRB) storage,
9. External Tank (ET) Checkout Cells,
10. ET Storage Cells,
11. ET barges for shipment to KSC,
12. ET production rate, and
13. workshift schedules.

These factors were chosen both for their expected degree of effect on the launch rate of the system and for their ability to be altered.

The ground system at VAFB is designed such that it would be difficult to vary any of its facilities. The system, in fact, is not designed to easily provide for increased number of launches. Therefore, none of its factors were varied in its Q-GERT model. This area is further discussed in upcoming sections of this chapter.

Having chosen the factors, our next concern was to determine the levels that each of the factors could obtain. Factors one through eleven are such that they are added by integral amounts. The beginning levels for each of these factors was determined by the number that each was expected to have at the end of 1986 and are given in chapter II. Thereafter, the level of each factor was increased as required. Factor twelve was considered at three levels. The first level was the current estimated capability of 24 ETs per year, the second level was the future planned rate of 40 per year, and the last level is 60 per year. The last rate is the rate the system was originally designed to ultimately achieve. Factor thirteen was also considered at three levels. The starting level was that which was used for the analysis in the STAR (that is, two shifts for five days a week). The next level was an increase to three shifts for five days a week, while the last level was set at three shifts for seven days a week (around the clock operations).

Additional Concerns. For thoroughness sake, it would be best to determine the launch rate under all of the various possible combinations of the factors described above. However, the number of runs of the system required would be prohibitively large. For example, if factors one through eleven had only two levels then the number of runs of the system required to examine all of the possible configurations would be $18432 (2^{11} * 3^2)$. Therefore, it was desirable to reduce the number of

configurations to be examined. For the majority of the runs it was anticipated that there would be a single limiting factor and thus it would be ineffective to add to the other factors. Therefore, in addition to the number of launches per year, the model must output information on resource usage and identify which components are delaying launches and where the delays are occurring. This output would allow efficient analysis of the system and enable resource addition to only those factors which will improve the launch rate. This result greatly reduces the number of runs required and thus saves computer time and money.

Finally, the model must output information, such as the variance of the means, to be used in the statistical testing of the results.

In summary, the model must output the number of launches per year or give an equivalent output which can be used to calculate that value. It must also allow the input of the various levels of the factors mentioned, and it must output information on the usage of the various factors. Finally, it must indicate where components are delayed, and it must output the data required to perform statistical analysis.

Q-GERT Simulation Techniques

Once the experimental design considerations mentioned above were identified, the next step was to determine which simulation technique was best suited for the study. This section describes the Q-GERT technique selected and includes a brief history of the method. This technique was selected for its compatibility with the design criteria previously mentioned. A brief description of the main facilities of Q-GERT that led to its selection are presented.

Q-GERT Description. Q-GERT, as described by its originator,

A. Alan B. Pritsker, is a "network modeling vehicle and a computer analysis tool" (Ref 7:vii). GERT stands for Graphical Evaluation and Review Technique, while the Q indicates that the technique allows for the modeling of queues in a system. Q-GERT was designed to support the systems approach to problem resolution. This approach consists of decomposing the system into its significant elements, analyzing and describing these elements, integrating the elements into a network model of the system, and finally assessing the system performance through evaluation of the model (Ref 7:vi11). Q-GERT is therefore a method of both modeling and analyzing systems.

Q-GERT can be traced back to PERT (Performance Evaluation and Review Technique) and it is in fact a direct descendant of that method. PERT was developed to show sequencing of activities and was an activity-on-branch representation of networks. Nodes were then introduced to allow scheduling and decision points in the network and from this GERT was developed. GERT went through various stages, including GERTS, GERT II, GERT IIIZ, and others. Eventually, from these methods Q-GERT was developed. The brief history given above was gleaned from Pritsker's Modeling and Analysis Using Q-GERT Networks. (Ref 7:11-26). If more information on the history of the development of Q-GERT is desired, the reader is referred to the above book.

Q-GERT network modeling is based on an activity-on-branch philosophy (Ref 7:3). This philosophy indicates that transactions flowing through the network move down branches that represent activities such as processing times and delays. Branches are separated by nodes which represent decision points, milestones, or queues. At the nodes, decisions are made on branches to be taken (if any), information such as arrival time and processing time is kept, and/or transactions are

held awaiting server availability. Q-GERT allows both serial and parallel processing of transactions.

As indicated in this description, Q-GERT has two basic functions. First, Q-GERT provides symbology for constructing a graphical network model of a system. This symbology allows the user to communicate visually their representation of the system. The second function of Q-GERT is to provide a computerized code to translate the graphical model into a computer readable language so that analysis can be conducted. The methodology also provides an analysis program which utilizes the model code. The Q-GERT Analysis Program is written in ANSI Fortran IV. There is, however, a separate set of Q-GERT instructions that allows the user to easily code the model for analysis by the analysis program. In this sense, Q-GERT can be considered a simulation language.

Therefore, Q-GERT provides a methodology for constructing and analyzing simulation models of network systems.

Q-GERT Facilities. This section describes some of the Q-GERT facilities that led to its choice as the simulation technique for this study. The discussions are brief and if further, more detailed information on the facilities is desired the reader should refer to Pritsker's book (Ref 7).

First, Q-GERT allows for both user directed and automatic collection of statistics. There are five types of statistics that can be requested by the user. They are the time of first release of a node (first), the time of all releases of a node (all), the time between releases of a node (between), the time between the marking of a transaction and the release of a node (interval), and the time that trans-

actions wait at a node for the arrival of other transactions needed to cause node release (delay). For this study the statistics of interest are the between and the interval statistics. The between statistics are used to determine the time between launches (which can be converted to the average annual launch rate). The interval statistics are used to collect information on the average processing time for the Orbiter in the OPF. In addition to the user requested statistics, statistics are automatically collected and output for various types of nodes. At queue nodes, statistics on the average number in the queue and the average waiting time in the queue are collected. These statistics are used to help determine where components are waiting for resources or for other segments of the system to clear. These statistics can therefore be used to help determine the limiting factor in the system. Thus the statistics facilities provide the output of the desired response variable and the information needed to determine limiting factors.

A second facility of Q-GERT allows for the designation of resources that are limited in number. This facility is used for nearly all of the factors of interest, since they are all of limited number. This capability allows for the delay of transactions due to a lack of available resources. In addition statistics are automatically collected on all designated resources. These statistics include the average number of resource units utilized and their availability over the run of the system. This information is used to help determine limiting factors in the system.

Next, Q-GERT allows for the marking of transactions with attributes. These attributes can be used in making branching decisions at nodes and for keeping track of various types of transactions flowing through the system. In this model, the attributes are used to number Orbiters, keep

track of the number of missions that each Orbiter has been on, identify payload types, and to hold information on branches to be taken. The mission number is used to determine what type of special maintenance, if any, is to be conducted on the Orbiter in the OFF. The payload types are used to determine the type of activities to be conducted in the OFF and to determine the length of the mission. This facility allows for a consistent sequence of activities for each use of the Orbiter. Without this facility, probabilities would have to be relied on, thus adding more uncertainty to the model.

Another useful facility of Q-GERT is the availability of assembly nodes. These nodes hold transactions in queues until one of each part of an assembly is available and then combines the transactions, thus simulating assembly of the units. There are numerous points in the STS system where this type of facility is required. Such points are SRB and ET assembly, and Orbiter mating to an SRB/ET assembly. With the transactions waiting in queue nodes for the arrival of the component to which it will be assembled, the automatic collection of statistics will indicate which item is delaying the assembly. This information will help determine the limiting factor in the system.

Q-GERT utilizes a next event time keeping system rather than a fixed interval time keeping scheme. This is most appropriate for this study since the transactions move from node to node and do not alter processing time once on a particular branch. A fixed interval time system is not required since the transaction movement is the concern of this model and not the changes of the system over time. With fixed interval, an activity could be completed in the middle of a time period, but the model would not see the completion until the end of the period.

This result could cause a loss in timing accuracy and affect the results of the study. Compensation for this problem would require the setting of the fixed interval at a value sufficiently small to reduce the possible errors. This action would, however, greatly increase the computer time required to run the system. In general, the next event time keeping system is used when the analyst is interested in what happens to the individual items in the system (Ref 25:110). Therefore, this time keeping scheme is the method most appropriate for this study.

Additionally, Q-GERT provides a variety of distributions that can be utilized in a model. The distributions of interest in this study are the normal, the uniform, and the Beta-PERT. This facility provided the major ability that was not available for use with the analytical model, that is, the ability to estimate the variability of the system. The specific ways that these distributions were utilized is further discussed in the parametric model descriptions.

Finally, Q-GERT allows the user to add special user defined functions and subroutines to accomplish tasks not provided for in Q-GERT. The two areas used in this model were the User Function(UF) and the User Input (UI) Subroutine. Subroutine UI was used to initialize values that were required at the beginning of each run. This subroutine is automatically called by Q-GERT at the beginning of each run of the model. UF is entered when requested at a node or activity in the Q-GERT model. Numerous functions can be contained in UF. The specific function to be entered is determined by the value of the argument given by the user. Some of the specific uses of UF in this study were to set the initial number of missions for each Orbiter, to determine the type of payload, to determine when to send ETs and Orbiters

to VAFB, and to delay other VAB activities when SRB stacking was occurring in the VAB. In addition to these facilities, Q-GERT has many intrinsic functions and subroutines that can be used in the user designed functions and subroutines. The availability of these items allows the user to reduce the size of user designed programs, thus simplifying the programmer's job.

Therefore, primarily for the reasons listed above, the Q-GERT simulation technique was selected as the technique to use in this study.

Structural and Parametric Models

The next step in the research design process was to design the simulation models. This section describes the structural and parametric models utilized for analysis.

Prior to the description of the models, an explanation of the reason for the two models, one for KSC and one for VAFB, is given. The primary reason for separating the two into different models is the difference in the design of the two ground systems. The allowable launch azimuths out of VAFB are only good for high inclination polar type orbits. Since only a limited number of payloads will require this orbit, VAFB was designed to handle only a few launches per year. The VAFB ground system was not designed to allow for increases in capacity and is basically fixed in its launch capabilities. Because the Shuttle is assembled on the pad at VAFB, the only way to increase VAFB launch rates is to decrease the activity times or duplicate most of the facilities. Therefore, the launch rate at VAFB was considered to be constant. VAFB was modeled to determine this launch rate and to determine the processing times for an Orbiter at VAFB. This informa-

tion was then used in the KSC model to model the draw off of resources for VAFB operations. In summary, this study does not look at increasing the STS launch rate at VAFB, since increasing it beyond current capabilities would require the obvious duplication of most of its facilities.

VAFB Structural Model. The assumptions made in this model are the same as those listed in the VAFB Shuttle Turnaround Analysis Report (VSTAR 05). ground rules (Ref 21:62-64). Chief among these assumptions is that ETs and SRBs are available when required and that there is a single Orbiter dedicated for VAFB use. In addition, this study assumes that there is a single barge dedicated to ship ETs from the Michoud production plant to VAFB, and that this barge can carry four ETs per trip. Q-GERT graphical and computerized representations of this model can be found in Appendix B. The node numbers and activity numbers referenced in this description are from that graphical model. The model was developed using the information contained in VSTAR 05.

The supply of ETs required for the complete run of the model are generated (node 51 and activity 1) and then they wait at the Michoud facility (node 1) for the barge to become available. When the barge becomes available, four ETs are shipped to VAFB (activity 5) where they wait for checkout and storage (node 5). When a transport (one available) and ET storage (four available) become free, an ET is offloaded (activity 6), transported to the ET checkout facility (activity 7) and inspected (activity 8). The ET then waits for the checkout cell (node 13) and the transport is returned to the barge (activity 10). If there is one or three ETs remaining to be unloaded, then another ET is unloaded (activity 20) and moved as above. If there are two ETs still on the barge, the

ET transportation kits from the first two ETs are loaded onto the barge (activity 19) before the next ET is unloaded. If no ETs remain to be unloaded, the last two ET transportation kits are loaded onto the barge (activity 15) and the barge is returned to Michoud (activity 16). When the barge reaches Michoud (node 22), four more ETs are loaded and the process is repeated.

When the ET checkout cell is free (one available), the ET is checked out (activities 11, 12, and 13). After that, the ET is returned to storage where it waits to be used (node 28). The ET checkout cell is then prepared for the next ET (activity 22), after which it is made available for use (node 26).

The Orbiter is generated (node 53) and waits (node 31) for the Orbiter Maintenance and Checkout Facility (OMCF) to become available. When this facility is free (one available), the Orbiter is moved into it and prepared for launch (activity 27). After that, the Orbiter waits in the OMCF (node 34) until it is needed at the pad for mating with the SRB/ET assembly.

When a SRB/ET assembly becomes available, the Orbiter is moved to the pad and OMCF is freed (node 37). The Orbiter is mated (activity 29) and then pad operations are conducted (activity 32). Upon completion of the pad operations, the Shuttle Vehicle is launched (node 40) and the time between launches is retained.

The Orbiter conducts its mission (activity 33), after which it lands at VAFB. If the landing strip is in use, the landing is delayed (node 42 and activity 34). When the landing strip is free, the Orbiter lands and post landing operations are performed (activity 35). The Orbiter is then moved to the safing and deservice facility

(node 29) where it is safed (activity 25). The Orbiter is then towed to the OMCF (activity 26) where it waits (node 31) for the OMCF to become available.

After launch, the launch pad is refurbished and prepared for the next SRB stack (activities 36 and 37). The SRBs are then stacked and verified (activity 39), after which the assembly waits for an ET (node 45). When an ET is available, the ET is moved to the pad and the ET storage cell is freed (node 48). The ET is mated to the SRBs (activity 43) and the assembly then waits for an Orbiter (node 50).

VAFB Parametric Model. The parametric model used for the VAFB system was determined from the data contained in VSTAR 05 (Ref 22). This report provides both allotted and assessed times for the various activities. The activities given in VSTAR 05 are presented in terms of the work hours required to complete the various tasks. The ground rules for the assessment of the turnaround is based on two work shifts operating for five days per week. Since the desired output of the model is a measure of yearly launch rate and the output of the structural model is given in time between launches, the activity times need to be converted to a form which can be used to produce the desired results. The yearly launch rate can be determined by dividing the number of days in a year by the average time between launches (in days). It was therefore desirable to convert the work hours to days. Working two shifts for five days per week equates to 80 hours per week or 11.428 hours per day. Dividing the work hours by this figure gives the number of 11.428 hour days required to complete the task. For example, if a task requires 20 work hours to complete, it takes $20 \text{ hours} / 11.428 \text{ hours per day}$, or 1.75 days to complete.

The next requirement was to determine the distribution(s) to use

in the model. For most of the activities there was very little difference between the allotted and the assessed times given in the VSTAR 05. Due to this fact, and the fact that the times are a compilation of many individual sub-tasks, it was decided that a normal distribution should be used for most of the activities. The average of the allotted and the assessed time was used as the mean of the distribution, and one half of the difference between them was used as the standard deviation of the distribution. Had the model been based on the many individual sub-tasks, the overall distribution which would result would tend to look like a normal distribution as indicated by the Central Limit Theorem (Ref 30:181-185). This selection of distributions was tested against other possible distributions to determine how this selection affects the results of the model. The results of this analysis are reported in Chapter VI.

There were some parameters that were not listed in VSTAR 05. One of these parameters was the mission time. The distribution used was the same as the nominal mission that is presented in the KSC parametric model and therefore discussion is deferred on it until then. Another parameter not in VSTAR 05 is the shipping time for the ETs from Michoud to VAFB. Conversation with Michoud ET personnel indicated that the shipping time would be between 25 and 30 days one way. (Ref 23). Lacking further information, a uniform distribution was used with the minimum and maximum times set equal to the figures given above. Finally, there were some activities which had assessed times equal to their allotted times. ET transport time to the pad is one such time. These activities were given constant distributions.

KSC Structural Model. This section describes the model used to simulate the KSC STS facilities. The facilities included in this description are those that are used as the starting points of the study. The node and activity numbers referenced in this section are those listed in the Q-GERT network for KSC. This network and its computerized representations are found in Appendix A.

Prior to describing the model, one of the important assumptions should be discussed. The assumption that SRB production and refurbishment facilities can supply the number of SRBs required for the various launch rates is made for two reasons. First, the modeling of the SRB retrieval and production system would add great complexity to the model, but would not provide much more insight into the system. The reasons for this result are that the model would have to make many assumptions on component lifetimes, probabilities of loss, and distributions of lifetimes. These factors would have to be estimated with little or no data available to use in doing so. Secondly, it was found during literature searches that detailed studies have already been done on this subject (Refs 26; and 27). That research produced a model of the SRB system, BOSIM (Ref 26). This model has been used to determine the number of SRB components needed to reach various launch rates. Results from this model for a 445 launch traffic schedule can be found in James V. Butler's SRB Subsystem Quantities for 1979-1991 Shuttle Operations (Ref 27). Our study of KSC operations could not provide further insight into the SRB area, and, in fact, the modeling of the SRB retrieval and production system could decrease the reliability of the model. Therefore, the assumption was made that SRB production is sufficient to provide SRBs to KSC when required.

At the beginning of the structural model, the initial Orbiters (three at KSC) are generated (node 1), and an additional one is generated at VAFB (node 31). At these points, the Orbiters are numbered (attribute 2), the number of missions each will have by the start of fiscal year 1988 is determined (using UF 1) and stored in attribute 1, and the initial down payload is set (attribute 3). UF 1 contains the number of flights each Orbiter will have by fiscal 1988 and is based on the current flight manifest (Ref 9). The Orbiters then wait (node 2) for an OFF bay to become available (node 3).

When an OFF bay is freed (two available), the Orbiter moves into it and required Orbiter servicing begins (nodes 4 through 27). First the up payload is selected (UF 4). The payload is selected using cumulative probabilities calculated using the shuttle manifest and a Monte-Carlo sampling technique. (Ref 9). The payload types considered are the following:

1. Spacelab,
2. Horizontally installed (non-Spacelab), and
3. Vertically installed (payload inserted at the launch pad).

once the payload selection is made, the Orbiter is safed and deserviced from its previous flight (activity 4).

From this point four parallel Orbiter activities take place in the OFF. The first set of activities (nodes 6 through 11) is payload related. First the down payload is removed (activity 5 or 6) and then the up payload is loaded and serviced (activities 7, 8, 9, or 10). The particular activities that are conducted depend on the payload type. Finally, the final system verification is conducted (activity 11) and then the Orbiter waits for the maintenance activities to be completed

(node 11). The second path in the OFF is concerned with Space Shuttle Main Engine (SSME) maintenance. The routine SSME maintenance is conducted (activity 12), and the Orbiter then waits for the completion of any Periodic Significant Scheduled Tasks (PSSTs) (node 12). The SSME PSSTs are accomplished at various flight intervals and are conducted in parallel with the routine SSME maintenance. The type of PSST to be completed is determined by the mission number for the Orbiter (using UF 5), and is then performed (activity 14, 15, 16, or 17). When the PSSTs are completed, the Orbiter waits for the routine maintenance to be completed (node 14). When all of the SSME maintenance is completed, the two transactions are combined and the new transaction waits (node 17) for the other OFF activities to be completed. The third parallel path is the Orbiter scheduled maintenance. The routine maintenance (activity 15) is conducted in parallel with Orbiter PSST maintenance (activity 21, 22, 23, 24, or 25). Which type of Orbiter PSST (if any) is conducted depends, like the SSME PSST, on the number of missions that Orbiter has completed (using UF 6). When both the routine and PSST Orbiter maintenance is completed, the Orbiter waits (node 23) for the other OFF activities to be completed. The final parallel activity is the Thermal Protection System (TPS) maintenance (activity 27). When this activity is completed, the Orbiter waits (node 24) for the other OFF activities to be completed. When all four of the types of Orbiter maintenance are completed, the time the Orbiter was in the OFF is recorded (node 26) and the Orbiter waits in the OFF (node 27) for an SRB/ET assembly to become available in the VAR.

The next portions of this section will describe the SRR, ET, and VAB portions of the model.

The initial aft skirts for the SRBs are generated (node 51) and wait (node 52) for the PSF (one available) to become available (node 53). When the PSF is free, the aft skirts (one pair at a time) are mounted on the stands (activity 53) and wait (node 55) for the SRM canisters to arrive (SRM canisters wait at node 56). When both are available, the aft skirt and the aft SRB segment are mated (activity 55). This assembly then waits for storage to become available (node 58). When storage is free (two bays available), the assembly is moved into it (node 63) and the PSF is freed (node 61) for the next SRP set.

Three MLPs are generated (node 64) and wait for a VAB High Bay (node 65). When a High Bay is free (two available), the MLP is moved into it and prepared for SRB stacking (activity 62). If SRB stacking is taking place elsewhere in the VAB, the MLP activity is delayed (using UF 11) until the stacking is complete. When the MLP preparation is complete, the MLP/VAB set waits (node 68) for a SRB pair to become available for stacking.

When both a SRB pair and a MLP/VAB set become available, the SRB pair is moved into the VAB and the SRB storage bay is released (node 96). SRB stacking then begins (activity 64). Since SRB stacking is a hazardous operation, all other VAB activities (activities 32, 62, 65, 69, 70, and 77) are delayed until the stacking is complete (using UF 9). After stacking is complete, SRB verification is conducted (activity 65), after which the assembly waits (node 72) for an ET to become available for mating.

The ETs are produced at a rate of 24 per year (node 79 and activity 71). ETs are then selected to be sent to either KSC or VAFB (node 80). This decision is made (using UF 8) on the basis of sending

ten ETs per year to VAFB (ten is the figure obtained from the analysis of the VAFB model and projected flight schedules). The ETs to be sent to KSC wait (node 81) for a barge (four available). It is assumed that there is a separate barge available to send ETs to VAFB. When a barge becomes available, the ET is shipped to KSC (activity 74). When the ET arrives at KSC, it waits (node 84) on the barge for an ET checkout cell to become available (two exist). When the checkout cell becomes available, the ET is offloaded and the barge is sent back to the Michoud facility (activity 75) for further use (node 87). The ET is then processed through the checkout cell (activity 77). This activity is delayed when SRB stacking operations take place (using UF 15). When the ET processing is complete, the ET waits (node 89) in the checkout cell for a storage cell to become available (two exist). When a storage cell is freed, the ET is moved to it and the checkout cell is freed (node 92).

When an ET and a SRB assembly are both available, the ET is moved to the MLP/SRB assembly and the storage cell is freed (node 75). The ET is then mated to the SRB assembly (activity 69). This activity is delayed (using UF 14) during SRB stacking operations (in the other High Bay). After mating, the SRB/ET assembly is checked out and verified (activity 70). Again, this activity can be delayed by SRB stacking operations (using UF 14). When verification is complete, the SRB/ET assembly waits (node 78) for a serviced Orbiter to become available.

When both an Orbiter (waiting in the OPF, node 27) and a SRB/ET assembly are available, the Orbiter is moved to the VAB (activity 30) and the OPF bay is freed (node 29). The Orbiter is then mated to the SRB/ET assembly (activity 32). This activity is delayed (using UF 10) when SRB stacking operations take place in one of the other High Bays.

When the mating is complete, the Shuttle Vehicle waits (node 32) for a crawler (one available) and then waits (node 34) for a launch pad (two available). When both are available, the shuttle is moved to the pad (activity 33) and the VAB High Bay is freed (node 98). After arrival at the pad, the crawler is returned (activity 34) and freed for further use (node 38). Pad operations are then conducted (activity 36), after which the shuttle is launched (node 40). The mission number is incremented and the time between successive launches is retained.

After the launch, the pad is refurbished (activity 37), and then freed for further use (node 41). The MLP is washed down on the pad (activity 61), after which it is moved to the VAB where it waits (node 65) for its next use. As mentioned in the SRB assumptions, the SRB components are immediately returned (activities 53 and 54) for further use.

The Orbiter conducts its mission (activity 40 or 42, depending on the payload type) and then prepares to land. This model assumes that the Orbiter lands at the site from which it will next be launched. The landing site is determined (using UF 7) such that ten Orbiters per year go to VAFB. If the Orbiter is to land at KSC (activity 42), the landing strip is checked to see if it is free (node 45). If the strip is in use, the Orbiter landing is delayed (node 46 and activity 43). If the strip is free, the Orbiter lands and the post landing activities are accomplished (activity 44), after which the Orbiter is moved to the OPF for servicing (node 2).

If the Orbiter is to land at VAFB (activity 45), the VAFP landing strip is checked (node 47) to see if it is free. If not, the landing is delayed (node 48 and activity 46). If the strip is free, the landing

and post landing operations are conducted (activity 47), after which the Orbiter waits to be used (node 49). The Orbiter is then processed for launch (activity 48), and finally launched (node 50). The number of Orbiter missions is updated and the time between missions is retained. The Orbiter then conducts its mission (activity 49), and when it is finished, the landing site decision (node 44) is made as before. At the start of the run a single Orbiter is generated at VAFB (node 31).

KSC Parametric Model. This section describes the activity parameters used in the KSC model. The majority of the parameter data was obtained from the KSC Shuttle Turnaround Analysis Report, STAR 23 (Ref 12). This data, like the VSTAR data, is given in terms of allotted and assessed times.

As in the VAFB parametric model, the data is given in work hours and needs to be converted to days. This was accomplished in the same manner as was the VAFB data. Additionally, the KSC model allows for increased number of shifts above the nominal two shift, five day per week schedule. The additional levels considered are three shifts for five days per week, and three shifts for seven days per week. These convert to 17.143 and 24 hours per day, respectively. These values are used to convert the given work hours to days.

Unlike the VSTAR 05 data, the STAR 23 data shows wide differences between the allotted and the assessed times. In fact, the estimated overall turnaround time has an assessed value of 888 hours (77.7 days) compared to the design, or allotted, value of 160 hours (14 days) based on two shifts for five days per week.

Due to the lack of actual data to statistically fit known distributions against, it was decided to use the beta-PERT distribution provided by the Q-GERT Analysis Program for the majority of the

activities. This distribution was chosen because it does not require a calculation of the mean or standard deviation of the distribution. Instead, the beta-PERT uses estimates for the most likely (m), optimistic (a), and pessimistic (b) times to calculate the mean $(a + 4m + b)/6$ and the variance $(b - a)^2/36$ used in conjunction with the beta-PERT distribution (Ref 7:204-208).

It was assumed that the assessed times given in the STAR were the most likely values for the activity times. The allotted times in the STAR are based on the design turnaround time of 160 hours and these were therefore taken to be the optimistic times. There was no data in the STAR on which to base the pessimistic times. Therefore, it was decided to make them symmetric with the optimistic times around the most likely times. Personnel responsible for preparing the STAR were contacted and their opinions solicited. Such conversation indicated that the above choices for most likely, optimistic, and pessimistic times were as good a guess as any (Ref 28).

It was recognized that the selection of the optimistic and pessimistic times could affect the outcome of the model. Therefore, sensitivity analysis was performed on them and the results of that analysis are presented in Chapter VI.

Although the majority of the parameters in the STAR were modeled using the beta-PERT distribution, there were some parameters which had allotted and assessed times which were nearly equal. Some of these were MLP and pad refurbishment times, and transportation times for moving shuttle components between the various facilities. For these activities, the times were taken as constant and equal to the minimum of their allotted or assessed times.

As with the VAFB model, there were some parameters that were not presented in the STAR. Specifically, these were the ET shipping times, the Orbiter mission times, and the Orbiter use time at VAFB. For the ET shipping time, the personnel responsible for the ET were contacted and they indicated that this activity would take seven days (Ref 23). This was used as a constant time in the model. For the mission times, it was determined that there are two basic sets of mission times. One time would be for Spacelab missions. Power extension packages are planned for development and use. These packages can extend the maximum shuttle endurance time from 14 days to 30 (Ref 29:20). The primary use of these packages would be to extend Spacelab mission time. Based on this information and our recollections of projected Spacelab mission times, it was decided to use a normal distribution with a mean of 12 days to model these mission times. The standard deviation was chosen to be 3 days, and the minimum was set at 7 days and the maximum at 30 days. Literature dealing with the other types of missions indicated that an average mission time of 4 to 5 days was expected (Ref 5:22; and 12:7-16). Therefore, the mission times for all non-Spacelab missions were selected using a normal distribution with a mean of 4 days, a standard deviation of 1 day, a minimum of 2 days, and a maximum of 7 days. The expected value of the Orbiter mission time, found by multiplying the means of 12 days and 4 days times their respective ratios of occurrence, is equal to 5.376 days. Finally, the time an Orbiter spends at VAFB was obtained from runs of the VAFB model. This time was also found to be normally distributed.

A table which contains all of the activities and their parameters can be found in Appendix A. This table gives the data in work hours

and in days for each of the work shift levels discussed.

Experimental Design

Once the research considerations and the models were developed, the next step in the research design process was to determine the actual experimental design to use to obtain the desired output and to analyze the results. This section describes the methodology used, and includes the statistical testing techniques used on the results.

The first consideration was to determine the starting conditions of the model and how to account for the possible effects of these starting conditions. The starting conditions selected include those facilities and hardware that are scheduled to be available by fiscal year 1988. Startup conditions were expected to have some affect on the outcome of the model and therefore it was decided to ignore the first year (365 days) of operations for statistical collection purposes. Since the expected turnaround time is about 80 days (based on STAR 23 data), the system should go through at least four complete cycles, and any affect the startup conditions have on the overall statistics should be minimized. It was found that the elimination of greater amounts of the startup data from statistical collections did not decrease the variance of the output. Therefore, the model was well into steady state operation after the first year of each run.

The next questions that were addressed were the length of each run and the number of runs to choose in order to accurately characterize the mean of the time between launches. Since the expected life of the system was originally anticipated to be about ten years, this value was used for the length of each run. In addition, it was felt that ten runs of the system were adequate to accurately characterize the mean.

Both of these values were somewhat arbitrary. Therefore, sensitivity analysis was conducted on them to determine if longer or more runs would provide significantly better results. Increasing either number would, of course, increase computer run time and cost. The results of this analysis is presented in Chapter VI.

Prior to describing the methodology used in this study, an assumption made for this analysis should be discussed. This assumption is that it is better, that is more cost effective, to add work shifts to a facility than it is to add a whole new facility. The reasoning behind this assumption is simple. Both of these options require the hiring (and paying) of additional work crews. Although the addition of a new facility may require the hiring of fewer workers, the costs of construction and maintenance would probably drive total life cycle costs above those of the option of more fully utilizing the existing facility. This philosophy was found to be compatible with NASA philosophy in telephone conservation with NASA personnel (Feb 28). Therefore, although both options can increase the launch rate, this study accepts the philosophy of increasing the number of work shifts in a facility before adding a new one.

Due to the way that the structural model was constructed and the type of output generated, the actual methodology used to analyze the results was relatively simple. The next few paragraphs give a description of the basic methodology used on the results.

Once the starting model was run on the computer and the output obtained, the first task was to determine the launch rate that the system was capable of under the starting conditions. This determination was accomplished by dividing 365 days by the mean time between launches

(the value under the output average column for node 40). This calculation yields the average launch rate in launches per year.

Next, using the queue node and resource statistical portions of the output, the results were analyzed to determine which factor(s) was/were limiting the launch rate. The resource utilization statistics give the average number of each of the resources that are in use during the runs. When this value approaches the maximum number available, that resource may be a limiting factor. The queue node statistics give the average number of transactions in the queue and the average number of days that the transactions wait in the queue. This data is used to determine where transactions are waiting for resources or for other components for assembly. When two components are to be mated, the amount of time that each component waits in the queue before being assembled indicates which component is waiting for the other. The component that waits the shortest amount of time on the average is the component which is limiting that portion of the system. If transactions build up in queue nodes waiting for resources, the following resource may be limiting the launch rate. Once the limiting factor(s) has/have been identified, this factor is increased (first by adding shifts, if applicable) and the model is run again. If there are two or more factors that appear to limit the launch rate, each of the factors is increased on separate computer runs to determine which is the most effective in increasing the system launch rate. The launch rate is calculated and the analysis is conducted as before. This process is continued until the desired launch rate is reached. Since the original design goal of the STS called for a launch rate of 45 per year at KSC, this level was used as the stopping point for simulation effort (19:39-

40). A more detailed step-by-step example of this process is presented in Chapter VI.

In order to determine whether or not the results from two runs were statistically different, a method of statistically testing the results was required. Since the model output means and standard deviations, it was decided to use the pooled t-test of hypotheses to evaluate the results.

The object of the successive runs of the model is to increase the launch rate of the system. Therefore, the test to be conducted must be one that will determine if the launch rate from the first run is statistically larger than the launch rate from the second run. However, the mean and standard deviation given in the output is in terms of the average time between launches. Since the greater the time between launches, the lower the launch rate, the actual test that is required is one that tests whether or not the time between launches of the second run is less than that of the first run.

Before proceeding further with the description of the test statistics used, it should be noted that the tests used assume that the populations of interest are normally distributed. Since the result, time between launches, is the result of the sum of a number of independent random variables, the central limit theorem was assumed to be applicable and the final distribution was, therefore, assumed to be normal. A set of results were tested using the Kolmogorov-Smirnov test and it was found that there was no significant difference between the actual data and the expected data for a normal distribution. (Ref 2540). The results of this test can be found in Chapter VI. Therefore, the assumption of normality seemed to be appropriate for this

study. The test and equations described below are from Hines and Montgomery (Ref 30:287-289, 295-296, and 312).

As previously mentioned, the object of the statistical testing was to determine whether or not the means of two runs were equal. Therefore, the null hypothesis (H_0) is that the two means are equal ($u_1 = u_2$), where u_1 is the mean of the first run and u_2 is the mean of the second run. The alternate hypothesis (H_1) is that the first mean is greater than the second mean ($u_1 > u_2$). If the null hypothesis is rejected, then it is accepted that the first mean is greater than the second, and the launch rate of the second run is greater than that of the first.

The type of test statistic used to test these hypotheses depends on whether or not the variances of the distributions are equal. Therefore, before the means can be tested, the variances must be tested for equality. The test statistic used in this case is

$$F_0 = S_1^2 / S_2^2 \quad (1)$$

where F_0 is the test statistic, and S_1^2 and S_2^2 are the sample variances of the two distributions of interest. This variance is obtained by squaring the standard deviation given on the output for node 40. It should be noted that for this test the largest variance is placed in the numerator of Equation 1. This test statistic is then compared to the following point of the F distribution:

$$F_{\alpha/2, n_1-1, n_2-1} \quad (2)$$

where α is the probability of a type I error (0.05 was used in this study), and n_1 and n_2 are the number of observations for each distribution. In this study, $n_1 = n_2 = 10$. The value of the statistic is

read out of a F distribution chart. For this study and the above values of α , n_1 , and n_2 , the statistic used is

$$F_{0.025, 9, 9} = 4.03 \quad (3)$$

The displayed value was obtained from the table on page 600 of Ref 30. If F_0 is greater than 4.03, the null hypothesis is rejected and the variances are assumed to be not equal. If F_0 is not greater than 4.03, the variances are assumed to be equal.

Once the equality of the variances has been determined, the test on the means is conducted.

If the variances are equal, the test statistic is

$$t_0 = (X_1 - X_2) / (S_p * (1/n_1 + 1/n_2)^{\frac{1}{2}}) \quad (4)$$

where t_0 is the test statistic, X_1 and X_2 are the sample means of the two runs, n_1 and n_2 are as before, and S_p is the pooled standard deviation. S_p is calculated as

$$S_p = ((n_1 - 1) * S_1^2 + (n_2 - 1) * S_2^2) / (n_1 + n_2 - 2) \quad (5)$$

where S_1 , S_2 , n_1 , and n_2 are as described before. This test statistic is then compared to

$$t_{\alpha, n_1 + n_2 - 2} \quad (6)$$

Since α , n_1 , and n_2 are constant for this study, the above statistic is

$$t_{0.05, 18} = 1.734 \quad (7)$$

The displayed value was obtained from the table on page 596 of Ref 30.

If t_0 is greater than 1.734, the null hypothesis is rejected and the

first mean is assumed to be greater than the second, indicating that the launch rate of the second is greater than that of the first. If t_0 is not greater than 1.734, the first mean is not greater than the second and thus the second run did not show an increase in launch rate.

If the test on the variances indicates that they are not equal, the following test statistic is used:

$$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{\frac{1}{2}} \quad (8)$$

The variable values are the same as before. This statistic is compared to $t_{\alpha, v}$ where

$$v = \frac{((S_1^2/n_1) + (S_2^2/n_2))^2}{(S_1^2/n_1)^2/(n_1 + 1) + (S_2^2/n_2)^2/(n_2 + 1)} - 2 \quad (9)$$

If t_0 is greater than $t_{\alpha, v}$, the null hypothesis is rejected and the second mean is assumed to be less than the first mean, indicating that the launch rate of the second run is greater than that of the first run.

If t_0 is not greater than $t_{\alpha, v}$, the second run did not improve the launch rate.

The results of these tests are presented in Chapter VI and Appendix A. In addition, a detailed example calculation is presented in Chapter VI.

IV. Verification and Validation

The utility of this thesis effort depends on the validity of the simulation model, and the assumptions on which it is based. While it was not possible to validate the model's predictive properties with 100% certainty, steps were taken to insure it produced reasonable accurate projections of future STS capacity. Three steps were used in this validation process (Ref 25:210). First, the Q-GERT simulation runs were examined to verify that the model operated as intended. Next, the underlying assumptions and simulation results were examined for validity. Finally, the results were subjected to statistical testing, and sensitivity analysis was performed on the model's variables. The following paragraphs describe each of these steps in greater detail.

Verification

To verify that the simulation model behaved as intended, the features of the Q-GERT trace routines were used. These routines list the sequence in which activities are performed and portray the decisions, value assignments, and branching which occur at the nodes (Ref 7:194). These traces were obtained for various simulation runs and thoroughly examined. They revealed that the simulation model accurately reflected the various activities done on STS flight hardware, and properly routed the hardware through the various facilities. The trace routines also revealed that the limited capacities of the STS facilities were properly reflected in the launch processing sequence. Therefore, it was determined that the simulation model behaved as designed.

Validation

The validation of the simulation method was itself a multi-step process. The underlying assumptions, the model, and the simulation results were each examined for validity.

Assumptions. The assumptions discussed in Chapters I and III were all examined for veracity. The following paragraphs present the validation process for each of them.

The first assumption was that the facility upgrades and hardware procurement contained in current funding plans will be completed by 1988. This assumption does not affect the validity of the thesis. If the planned upgrades are not completed, they will simply have to be considered necessary additions to the facility/hardware procurements listed in the conclusions.

The assumption that no accidents occur to reduce the flight hardware available or to interrupt launch processing activities is, of course, a very optimistic one. Accidents are likely, and excess launch capacity should be provided to allow for the resulting capacity reductions. This excess capacity should be large enough to insure (with reasonable confidence) that the minimum launch rate needed is achievable. Unfortunately, the determination of how much excess capacity to acquire is a difficult task and is beyond the scope of this thesis effort. The recommendations contained in Chapter VIII identify this topic as an important follow on effort.

The activity times contained in the Shuttle Turnaround Analysis Report (STAR) were assumed to be the best available estimates of the actual times to be experienced when the system matures. As the people publishing the report are those tasked with providing realistic

estimates of these times, the times should be the best estimates available. However, only five launches have taken place, and launch processing activities are still on the steep portion of their learning curves. Therefore, adequate samples of actual activity times to statistically compare to the assumed (estimated) times do not exist. Consequently, sensitivity analysis was performed on the estimated activity times and their assumed distributions. The results of these analyses are presented in Chapter VI. As expected, the simulation results are very sensitive to changes in the estimated activity times, moderately sensitive to the degree of symmetry assumed for their distributions, and slightly sensitive to the spread (value of sigma) of the distributions about their means. Model sensitivity to the choice of distributions (beta-PERT, normal, etc) was comparable to the choice of sigma. Telephone conversation with KSC personnel indicated that the choice of a beta-PERT distribution with the most likely value set equal to the assessed value, the optimistic value set equal to the allotted value, and the pessimistic value set symmetric with the optimistic value about the most likely, is as good a guess as any. Several years of launch processing data will have to be accrued before the choice of distribution type can be based on an accurate fit of actual data. Chapter VIII contains a recommendation that the simulation runs be repeated when sufficient launch data becomes available to adequately characterize the actual distributions for activity times. (Refs 12; and 28).

The assumption that payloads are always available when needed for launch processing activities is defensible. Although unexpected delays in payload availability may occasionally affect launch processing,

flexible payload scheduling procedures and prompt identification of payload problems can minimize launch delays. At any rate, the addition of excess launch capacity would not resolve this type of problem. The assumption that the current flight manifest is representative of future manifests affects the number of flights requiring payload insertions in the OPF. The later process adds time to the Orbiter turnaround and affects the overall launch rate. Since the total number of flights scheduled for the STS over the next decade has been substantially decreased, the payload projections based on the higher launch rates are probably inaccurate (Ref 6). Therefore, the scheduled manifest for the next few years is probably the most representative of the types of payloads and their relative numbers.

The assumptions made about VAFB launch rates were also examined. The VAFB launch rate governs the number of ETs, SRB pairs, and Orbiters made unavailable for KSC use. The rate at which ETs and SRBs are used at VAFB affects the point at which ET and SRB production must be increased above current limits. The amount of time an Orbiter spends at VAFB affects the equivalent number of Orbiters available for KSC use. To determine VAFB's ability to meet scheduled launch rates, and to determine the amount of time that an Orbiter spends in launch processing activities, a Q-CERT simulation and analysis was done for VAFB (Appendix B). This analysis used the information contained in the VAFB Shuttle Turnaround Analysis Report (Ref 21). The same assumptions made about the activity times in the KSC report were made for the times in the VAFB report. The results of the VAFB simulation were used to characterize the data used by the KSC simulation to model the draw off of resources for VAFB operations. As scheduled VAFB flights will tax the

capacity of that launch site, the sensitivity analysis presented in Chapter VI showed that it made little difference to KSC operations if a shuttle Orbiter was dedicated to VAFB.

Finally, the assumption that the Q-GERT simulation techniques work as advertised was examined. The Q-GERT trace routines showed that the model behaved as described in the text (Ref 7). The fact that the use of past projections on shuttle turnaround times produced results that agreed with old projections of launch capacity indicated that the Q-GERT statistic collection methods work. Also, an analysis of the Q-GERT statistical techniques covered in the text indicated that they were appropriate. It was assumed without question that the Q-GERT simulation package available on the computer system used is the same as that described in the text.

Model. The KSC and VAFB Q-GERT simulation models in Appendices A and B appear to accurately portray the flow of shuttle hardware through the various facilities used for launch processing. Given the proper inputs, and given that the Q-GERT simulation package operates as advertised, the model output should accurately predict STS launch capacity. Inaccuracies could arise as a result of the assumptions made about the input, or from improper analysis of the computer results. The assumptions were discussed in the previous paragraphs, and the results are discussed in the following ones.

Results. To validate the results, they were compared to published and analytically derived projections of STS capacity, and the model variables were subjected to sensitivity analysis.

Projections of STS launch capacity show it as 24 launches per year with the facilities to be in place by 1988 (Refs 8,68; and 10,79). The

Q-GERT model was run with the activity times contained in STAR 17 (May 79) and the results gave a capacity of about 24 per year.

However, when the model was run using the activity times contained in the May 1982 STAR (STAR 23), the predicted capacity for KSC dropped from 17 launches per year to 12. Published capacity is unchanged and still listed as 24 per year, with 18 launches per year coming from KSC. Therefore, either the published capacity or the simulated capacity is incorrect. As the current flight manifest is based on achieving a launch rate of 24 per year by fiscal year 1988, the question of which figure is correct becomes a very important one.

The sensitivity analysis discussed in Chapter VI showed that the simulation results were slightly sensitive to the type of distributions and values of sigma chosen for the activity times. However, this sensitivity was not enough to account for the wide difference between the models projected capacity and the published capacity. The model was, however, very sensitive to the choice of most likely values for the activity times. These values were taken directly from the STARS, where they are listed as the assessed times for the various activities. The assessed values have grown considerable over the last couple of years. For example, the overall assessed time for launch pad operations has grown from 57 hours in STAR 17 to 320 hours in STAR 23. As these times are supposed to be the most accurate available estimates of the actual times to be experienced when the system matures (after flight 30), it appears likely that the current flight schedule is overly optimistic, and that the models projected capacities are more realistic (Refs 9; and 32). Not only that, but it appears likely that additional capacity will have to be added to the system to meet current flight schedules. There-

fore, the results contained in Chapter VII can be used now as a guide to adding the work shifts and facilities necessary to meet the current flight schedule.

Since there were no published projections of STS capacity which matched the results of the computer simulation, the simple analytic model presented in Chapter V was devised to provide results to compare the simulation results to. Unfortunately, it was not possible to build an analytic model which could properly account for the complex interactions among the facilities or for their limited capacities. Although the results provided by the simple analytic approach are somewhat inaccurate, they are good enough to compare to the simulation results to insure that the latter results have the appearance of accuracy. This final step in the validation process added significantly to our confidence that the simulation method produced accurate and useable projections of STS launch capacity.

V. Analytic Approach

The simple analytic method covered in this chapter was used to produce a launch enhancement plan similar to that obtained using the simulation method. Unfortunately, the simplifications made to allow the analytic approach prevent this model from properly reflecting the interactions among the various facilities. For example, the simulation model will not allow an Orbiter to leave the OFF bay until an ET/SRB assembly is available to mate it to in the VAB. The retention of the serviced Orbiter in the OFF prevents that OFF bay from being used to service the next Orbiter in line. This occurrence is a true reflection of reality. However, the analytic model ignores the fact that serviced Orbiters may remain in the OFF and assumes that service on the next Orbiter can begin immediately upon the completion of service on the previous one. This assumption causes the analytic model to overstate the capacity of the facility. Similar simplifying assumptions are made about the other STS facilities and hardware. Therefore, the plan produced by the analytic model is inaccurate and overly optimistic. However, in the absence of any published plan using recent STAR data, this analytic plan is accurate enough to compare to the simulation results to insure that the latter have the appearance of validity. This appearance of validity increases the confidence with which the simulation results can be used. The following paragraphs describe the analytic network used, the method used to compute facility and hardware capacities, and the derivation of the launch enhancement plan.

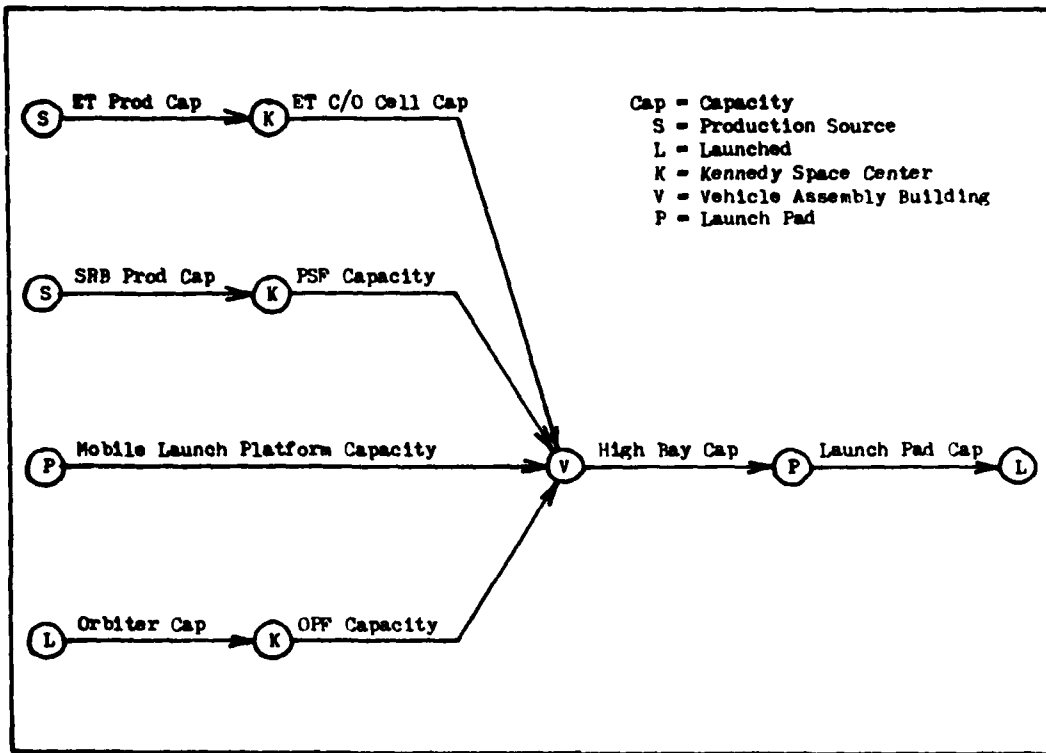


Figure 3. STS Analytic Network

Analytic Network

The analytic network used to model the STS launch processing flow is shown in Figure 3. This network takes into account the flight hardware needed to assemble a Shuttle Vehicle, and its flow through the various facilities in preparation for launch. The nodes represent the various facilities, and the branches represent their capacities. The interrelation of the branches and nodes is similar to that in a PERT diagram (Ref 18:487-491). All of the activities (branches) leading into a node must be completed before that node can be released. Also, all of the activities represented by the branches must be completed before a launch can take place. Therefore, the capacity of the system is equal to the least of the capacities along the branches.

Table I. Activity Times

Activity	Activity Time (hours/launch)	Source* (Figure #)
MLP Wash	62	14
MLP Refurb	39	14
SRB/ET (Stacking)	272	10
VAB (Orbiter Mating)	168	10
Pad Ops	320	6, 7
Pad Refurb	78	13
ET C/O	216	10
PSF Ops	272	11
Orbiter Turnaround Time (Verticle Payload)	840	7
Orbiter Turnaround Time (Horizontal Payload)	888	6
OFF Time (Vert Payload)	352	7
OFF Time (Hor Payload)	400	6

* (STAR 23, Ref 12)

Capacities

The capacities of the various facilities are calculated using the assessed times contained in STAR 23. Since symmetric distributions were chosen for the simulation model variables, their most likely values (STAR 23 assessed values) are also their mean values. Therefore, the use of the assessed values as the expected values of this analytic approach produces results which can be validly compared to the simulation results. The activity times contained in Table I were obtained from Figures 6, 7, 10, 11, 13, and 14 of STAR 23. These times were used to compute the capacities of the various facilities and flight

hardware. The remainder of this section covers the calculations of these capacities.

The capacity calculations are dependant on the work week schedule chosen. The standard work week used is two shifts, five days per week (2/5). The longer work weeks considered are three shifts, five days per week (3/5) and three shifts, seven days per week (3/7). Each shift is eight hours long, and the latter work week, (3/7), is an around the clock operation. No allowances are made for holidays. The various activity times are multiplied times a factor which reflects the work week chosen. This computation determines how many work days are required to complete an activity. The three work week factors are calculated as follows:

$$(2/5) = \frac{7 \text{ days per work week}}{80 \text{ hours per work week}} = 0.0875 \text{ days/hour} \quad (10)$$

$$(3/5) = \frac{7 \text{ days per work week}}{120 \text{ hours per work week}} = 0.0583 \text{ days/hour} \quad (11)$$

$$(3/7) = \frac{7 \text{ days per work week}}{168 \text{ hours per work week}} = 0.0417 \text{ days/hour} \quad (12)$$

VAB High Bay Capacity. In the process of assembling a Shuttle Vehicle in the VAB, certain hazardous operations take place. During these operations, the other VAB High Bays are evacuated. Therefore, the time it takes to assemble a Shuttle Vehicle can be extended by the requirement to perform hazardous operations in one of the other High Bays (Ref 12:7-11). The hazardous operations are Solid Rocket Motor (SRM) stacking (52 hours) and Orbiter hoisting (4 hours) (Ref 12).

If only one High Bay is used for vehicle assembly, no delays will result. The expected vehicle assembly time is therefore equal to

$$(MLP \text{ Refurb} + SRB/ET + VAB) \quad (13)$$

or, using the values in Table I,

$$(39 + 272 + 168) \text{ hours} = 479 \text{ hours} \quad (14)$$

If two High Bays are used, there is a chance that the hazardous operations in one bay will delay work in the other. However, if their operations are running in parallel, no delays will be experienced. This latter result can occur, since safety constraints do permit the simultaneous processing of two SRM sets (Ref 12:7-1). The ratio of hazardous operation time to total assembly time is

$$\frac{56 \text{ hours}}{479 \text{ hours}} = 0.117 \quad (15)$$

Assuming the start of assembly operations in the two High Bays are independent of each other, the probability that operations in one bay will be delayed by hazardous operations in the other is

$$1.0 - 0.117 = 0.883 \quad (16)$$

Therefore, the expected assembly time when two High Bays are used is

$$479 \text{ hours} + (0.883 * 56 \text{ hours}) = 528.45 \text{ hours} \quad (17)$$

When three High Bays are used for Vehicle Assembly, there will be at least a 56 hour delay due to the restriction on SRM parallel processing. A 112 hour delay will result when the three bays operate

out of sequence with each other. The probability that a 112 hour delay will occur is

$$\frac{479}{56} * \frac{(479 - 56)}{56} * \frac{(479 - 112)}{56} * (0.117)^3 = 0.677 \quad (18)$$

Therefore, the expected assembly time when three High Bays are used is

$$479 \text{ hours} + 56 \text{ hours} + (0.677 * 56 \text{ hours}) = 572.89 \text{ hours} \quad (19)$$

If four High Bays are used for vehicle assembly, delays of 56, 112, and 168 hours are possible. The 56 hour delay will always occur due to the restriction on parallel SRB processing. The 112 hour delay will occur when two bays operate in sequence while the other two operate out of sequence, or when three bays operate in sequence. The 168 hour delay will occur when all four bays operate out of sequence with each other. The probability of a 112 hour delay is equal to

$$\begin{aligned} & \frac{479}{56} * \frac{56}{56} * \frac{(479 - 56)}{56} * \frac{(479 - 112)}{56} * (0.117)^4 * 6 \\ & + \frac{479}{56} * \frac{56}{56} * \frac{56}{56} * \frac{(479 - 56)}{56} * (0.117)^4 * 4 = 0.523 \quad (20) \end{aligned}$$

The factors of 6 and 4 reflect the number of ways the two configurations which produce a 112 hour delay can occur. The probability of a 168 hour delay is equal to

$$\begin{aligned} & \frac{479}{56} * \frac{(479 - 56)}{56} * \frac{(479 - 112)}{56} * \frac{(479 - 168)}{56} * (0.117)^4 \\ & = 0.439 \quad (21) \end{aligned}$$

Therefore, the expected assembly time when four High Bays are used is

$$479 \text{ hours} + 56 \text{ hours} + (0.523 * 56 \text{ hours}) + (0.439 * 112 \text{ hours})$$

$$= 613.48 \text{ hours} \quad (22)$$

The VAB High Bay capacity is computed as

$$\frac{365 \text{ days/year}}{(\text{expected assembly time}) * 0.0875} * \# \text{ High Bays} \quad (23)$$

where 0.0875 is the work week factor for the (2/5) schedule. Capacities reflecting the other work week schedules, (3/5) and (3/7), are computed using the factors 0.0583 and 0.0417. The capacities for the four VAB configurations were calculated using Equation 23 and the results of Equations 14, 17, 19 and 22. These capacities are shown in Table II.

Table II. VAB High Bay Capacity

Work Week (shifts/hours)	Capacity in Launches per Year			
	1 Bay	2 Bays	3 Bays	4 Bays
(2/5)	8.71	15.79	21.84	27.20
(3/5)	13.06	23.68	32.77	40.80
(3/7)	18.29	33.15	45.87	57.12

MLP Capacity. The MLP capacity is calculate as

$$\frac{365 \text{ days/year}}{(\text{MLP Wash} + \text{MLP Refurb} + \text{SRB/ET} + \text{VAB} + \text{Pad Ops}) * 0.0875} * \# \text{ MLPs} \quad (24)$$

MLP Refurbishment, SRB/ET Stacking, and VAB Obiter mating operations are carried out in the VAB, while MLP Washing, and Pad Operations are carried out at the launch pad. If either of these facilities should go to a (3/5) or (3/7) work week schedule, the equation would change slightly. For example, the addition of a third shift in the VAB is calculated as

$$\frac{365 \text{ days/year}}{((\text{Wash} + \text{Pad}) * 0.0875) + ((\text{Refurb} + \text{SRB/ET} + \text{VAB}) * 0.583)} * \# \text{ MLPs} \quad (25)$$

Various strategies for increasing MLP capacity were investigated. Their capacities and their percentage increases over the nominal capacity (2/5 work week) are shown in Table III. Total MLP capacity is found by multiplying the chosen strategy by the number of MLPs available. For example, the three MLPs now available have a nominal capacity of $3 * 4.85$, or 14.53, launches per year.

Table III. MLP Capacity (per MLP)*

Strategy for Adding Work Shifts (shifts/days)	Capacity in Launches per Year	Percentage Increase over the Nominal Capacity
Nominal Strategy (2/5)	4.85	-----
(3/5) for Pad	5.69	17.4 %
(3/5) for VAB	5.95	22.8 %
(3/7) for Pad	6.31	30.3 %
(3/7) for VAB	6.84	41.1 %
(3/5) for VAB and Pad	7.27	50.0 %
(3/7) for Pad and (3/5) for VAB	8.32	71.8 %
(3/5) for Pad and (3/7) for VAB	8.64	78.3 %
(3/7) for Pad and VAB	10.17	110.0 %

* No adjustment for hazardous operations in VAB High Bays

Although the capacities listed in Table III reflect the relative merits of the various strategies, they do not adequately take into account the true capacity of the VAB. As discussed in the section on VAB High Bay capacity, Shuttle Vehicle assembly operations in one High Bay can be interrupted by hazardous operations in another High Bay. Since vehicle assembly operations take place on top of the MLPs, MLP capacity is reduced by these interruptions. The calculations of High Bay capacity revealed that VAB operations (MLP Refurbishment, SRB/ET Stacking, and Orbiter mating) are dependant on the number of High Bays configured for vehicle assembly. Equation 17 shows that the expected assembly time is 528.45 hours when two High Bays are used. Likewise, Equation 19 gives 572.89 hours as the expected assembly time when three bays are in use, and Equation 22 gives 613.48 hours as the expected

time when four bays are in use. The expected time when only one bay is used is 479 hours. This time is the one that was used to produce the results shown in Table III. To compute the adjusted values for MLP capacity, the expected values for High Bay operations were inserted in Equation 24 in place of the times represented by (MLP Refurb + SRB/ET + VAB). The capacities listed in Table IV are these adjusted values. Total MLP capacity is found by multiplying the listed capacity by the number of MLPs.

Table IV. MLP Capacity*

# High Bays Used	Strategy for Adding Work Shifts (shifts/days)	Capacity in Launches per Year
2 Bays	(2/5) for VAB and (2/5) for Pad	4.58
"	(3/5) for VAB and (2/5) for Pad	5.68
"	(3/5) for VAB and (3/5) for Pad	6.87
"	(3/7) for VAB and (3/5) for Pad	8.24
"	(3/7) for VAB and (3/7) for Pad	9.62
3 Bays	(3/7) for VAB and (3/7) for Pad	9.17
4 Bays	(3/7) for VAB and (3/7) for Pad	8.80

* Per MLP, when two or more High Bays are use

It should be noted from the last three lines above that the capacity of a single MLP decreases as the number of VAB High Bays used for Shuttle Vehicle assembly is increased. Therefore, an increase in the number of High Bays will force a more than proportionate increase in the number of MLPs.

ET C/O Cell Capacity. The ET C/O Cell capacity is computed as

$$\frac{365 \text{ days/year}}{(\text{ET C/O}) * 0.0875} * \# \text{ C/O Cells} \quad (26)$$

The ET C/O time (in hours per launch) was obtained from Table I. Table V contains the calculated ET C/O Cell capacities for the three types of work weeks.

Table V. ET C/O Cell Capacity*

Work Week (shifts/days)	Capacity in Launches per Year	
	1 C/O Cell	2 C/O Cells
(2/5)	19.31	38.62
(3/5)	28.97	57.94
(3/7)	40.56	81.11

* No adjustment for hazardous operations in VAB

However, the capacities in Table V do not allow for work interruptions caused by hazardous operations in the other VAB High Bays. Equations 17 and 19 reflect the additional time required to perform Shuttle Vehicle assembly as hazardous operations periodically delay High Bay operations. The ratio of ET C/O time to total vehicle assembly time is

$$\frac{216}{479} \quad (27)$$

By multiplying this ratio times the adjusted vehicle assembly times given by Equations 17 and 19, an expected ET C/O time is obtained.

This expected time reflects the delays caused by hazardous operations in the VAB. The adjusted times obtained are 238.30 hours for ET C/O when two High Bays are used for vehicle assembly, and 258.32 hours when three bays are used. The capacities shown in Table VI were obtained by substituting the adjusted times in place of the previously used 216 hours in Equation 26.

Table VI. ET C/O Cell Capacity*

# VAB Bays	Work Week (shifts/days)	Capacity in Launches per Year	
		1 C/O Cell	2 C/O Cells
2	(2/5)	17.51	35.01
2	(3/5)	26.26	52.52
2	(3/7)	36.76	73.52
3	(3/7)	33.91	**

* Adjusted for delays caused by the performance of hazardous operations in the other VAB High Bays

** The use of a third High Bay for vehicle assembly reduces the bays available for ET C/O to one.

PSF Capacity. The PSF capacity is calculated as

$$\frac{365 \text{ days/year}}{(\text{PSF Ops}) * 0.875} * \# \text{ PSF bays} \quad (28)$$

The calculated capacities for the PSF are shown in Table VII.

Table VII. PSF Capacity

Work Week (shifts/days)	Capacity in Launches per Year	
	1 PSF Bay	2 PSF Bays
(2/5)	15.34	30.67
(3/5)	23.00	46.01
(3/7)	32.21	64.41

Orbiter Capacity. The Orbiter capacity computation is made under the assumption that all ground operations take place on an around the clock basis (3/7 work week). This action enables Orbiter capacity limitations to be identified separately from facility limitations. The equation for computing Orbiter capacity is

$$\frac{365 \text{ days/year}}{(\text{Expected Turnaround Time} + \text{Expected Flight Time})} * \# \text{ Orbiters} \quad (29)$$

The current flight manifest shows that approximately 51.7% of the missions will require payload installation in the OFF (Ref 9). This activity increases the overall turnaround time by 48 hours to 888 hours. The rest of the missions (48.3%) will have their payloads inserted at the launch pad, and the assessed turnaround time for these missions is 840 hours (Ref Table I). The expected Orbiter turnaround time thus becomes

$$(888 \text{ hours} * 0.517) + (840 \text{ hours} * 0.483) = 864.82 \text{ hours} \quad (30)$$

or

$$(864.82 \text{ hours} * 0.0417 \text{ days/hour}) = 36.034 \text{ days/launch} \quad (31)$$

The expected flight time is computed using the flight time distributions assumed for the simulation model. Those were normal distributions with means of 12 days for Spacelab missions and 4 days for all others. The relative percentages for the two were based on the current flight manifest and are 17.2% and 82.8%. Therefore, the expected flight duration time is

$$(12 * 0.172) + (4 * 0.828) = 5.38 \text{ days/flight} \quad (32)$$

By plugging the results of Equations 31 and 32 into Equation 29, the computation of Orbiter capacity becomes

$$\frac{365 \text{ days/year}}{(36.03 \text{ days/launch} + 5.38 \text{ days/flight})} * \# \text{ Orbiters} \quad (33)$$

Orbiter capacity for various numbers of Orbiters is shown in Table VIII. An additional Orbiter is included for VAFB operations.

Table VIII. Orbiter Capacity

# Orbiters*	Capacity in Launches per Year
2	8.81
3	17.63
4	26.44
5	35.26
6	44.07
7	52.89
8	61.70

* Includes one Orbiter for VAFB

However, separate computations which take into account the work weeks used in the OFF, VAB, and on the launch pad were made. The capacities obtained were used in conjunction with the launch enhancement plan to show the need to quickly go to (3/7) work week schedules in the three facilities. The computations to calculate the capacities are similar to those used in computing MLP capacity. For example, Orbiter capacity with OFF, VAB, and Pad times of 376.82 (Equation 37 result), 168, and 320 hours, and a (3/5) work week, is

$$\frac{365 \text{ days/year}}{((376.82 + 168 + 320) * 0.0583) + 5.376 \text{ days/flight}} * \# \text{ Orbiters} \quad (34)$$

An additional correction was made while doing these computations. In the section on VAB High Bay capacity, it was shown that hazardous operations in one High Bay can delay normal operations in the others. The mating of an Orbiter to an ET/SRB assembly is one of the operations which can be interrupted. The number of High Bays used for vehicle assembly affects the expected delay. Equations 17, 19, and 22 take into account this delay and can be used to recompute the time it takes to route an Orbiter through the VAB. The ratio of Orbiter mating time to total vehicle assembly time is

$$\frac{168}{479} \quad (35)$$

Equation 17 gives the adjusted assembly time as 528.45 hours when two High Bays are used. For the use of three bays, Equation 19 gives 572.89 hours as the adjusted time. Finally, Equation 22 gives a time of 613.48 hours as the adjusted time when four bays are used for vehicle

assembly. By multiplying these numbers times the ratio in Equation 35, expected times for Orbiter VAB operations can be obtained. The calculated values are 185.32 hours when two bays are used, 200.93 hours when three bays are used, and 215.17 hours when four bays are used. These values are used in place of 168 hours in Equation 34 to obtain the results shown in Table IX.

Table IX. Orbiter Capacity

Work Week			Orbiter Capacity in Launches per Year**			
OFF	VAB*	Pad	2 Orbiters	4 Orbiters	5 Orbiters	6 Orbiters
(2/5)	² (2/5)	(2/5)	4.42	13.26	17.68	22.10
(2/5)	² (3/5)	(2/5)	4.73	14.19	18.92	23.65
(2/5)	² (3/5)	(3/5)	5.38	16.14	21.53	26.91
(3/5)	² (3/5)	(2/5)	5.52	16.55	22.07	27.58
(3/5)	² (3/5)	(3/5)	6.42	19.27	25.69	32.11
(3/5)	² (3/5)	(3/7)	7.09	21.26	28.35	35.44
(3/7)	² (3/5)	(3/5)	7.22	21.66	28.88	36.10
(3/7)	² (3/7)	(3/5)	7.69	23.07	30.76	38.45
(3/7)	² (3/7)	(3/7)	8.66	25.99	34.65	43.32
(3/7)	³ (3/7)	(3/7)	8.53	25.60	34.13	42.66
(3/7)	⁴ (3/7)	(3/7)	8.41	25.25	33.66	42.08

* The number in the upper left corner of each VAB entry is the number of VAB High Bays used for Shuttle Vehicle assembly.

** Includes one Orbiter for VAFB operations

OFF Capacity. The capacity of the OFF is dependant on the work week schedule. The equation for computing OFF capacity (assuming a (2/5) work week schedule) is

$$\frac{365 \text{ days/year}}{(\text{OFF time}) * 0.0875} * \# \text{ OFF bays} \quad (36)$$

Missions requiring payload insertion in the OFF extend OFF time to 400 hours. The OFF time for all other missions is 352 hours and the relative percentages of the two types of missions are 51.7% and 48.3% (Ref 9). Therefore, the expected OFF time is

$$(400 \text{ hours} * 0.517) + (352 \text{ hours} * 0.483) = 376.82 \text{ hours/launch} \quad (37)$$

This time was used in Equation 36 to produce the results shown in Table X.

Table X. OFF Capacity

Work Week (shifts/days)	Capacity in Launches per Year		
	1 Bay	2 Bays	3 Bays
(2/5)	11.07	22.14	33.21
(3/5)	16.61	33.21	49.82
(3/7)	23.25	46.50	69.74

Launch Pad Capacity. The equation for computing the launch pad capacity is

$$\frac{365 \text{ days/year}}{(\text{Pad Ops} + \text{Pad Refurb}) * 0.0875} * \# \text{ launch pads} \quad (38)$$

Using the activity times listed in Table I, the various launch pad capacities were computed. These results are presented in Table XI.

Table XI. Launch Pad Capacity

Work Week (shifts/days)	Capacity in Launches per Year		
	1 Pad	2 Pads	3 Pads
(2/5)	10.48	20.96	31.44
(3/5)	15.72	31.44	47.16
(3/7)	22.01	44.02	66.03

ET and SRB Capacities. The ET and SRB production rates are building towards 24 per year. Their production facilities are designed to allow the implacement of the additional equipment needed to bring their production rates to 40 per year. A greater effort would be required to increase the production rates beyond 40 per year (Refs 22; 23; and 24). This analytic approach assumes that the ET and SRB production rates are increased to the levels needed to meet the desired launch rates.

Launch Enhancement Plan

Tables II through XI were used in conjunction with the network shown in Figure 3 to develop the launch enhancement plan shown in

Table XII. At each step in the development of the plan, the facility or hardware with the least capacity was identified and capacity added to it. The process for adding capacity was to add work shifts before adding facilities. This process assumes that available resources will be fully utilized before additional facilities are constructed. The first line of the plan gives the current capacity of the STS at KSC. This capacity is based on the completion of current construction plans and includes:

1. 4 shuttle Orbiters (one of which is dedicated to VAFB),
2. 2 OFF bays,
3. 2 VAB High Bays (out of the 4 High Bays in the VAB),
4. 1 PSF bay (this facility also contains two storage bays),
5. 2 ET C/O Cells (positioned in two of the VAB High Bays),
6. 2 Launch Pads, and
7. 3 MLPs (assuming the third available MLP is reconfigured for STS use).

The configurations and capacities of each of these facilities and hardware are shown in the columns below the appropriate headings on Table XII. The first entry in each cell gives the units needed (bays, MLPs, etc) to produce the associated capacity. The second entry gives the work week schedule employed (if appropriate) and the lower entry gives the capacity of that configuration. The capacity for the overall configuration represented by a row in the Table is given in the left hand column. This overall capacity is found by locating the facility or hardware on that line which has the least capacity. The second column gives the corresponding capacity obtained from the simulation approach. To use the plan, locate the entry in the left

hand column which corresponds to the desired launch rate, and read off the configuration needed from the other columns in that row.

As can be seen by comparing the first two columns, the simulation results closely match the analytic results. The sequencing of facility and hardware additions are about the same and the corresponding launch rates are nearly equal. Therefore, the simulation results appear to be valid. This final step in the validations process greatly increases the confidence with which the more accurate simulation method and results can be used. However, the analytic method proved to be more accurate than expected. Therefore, it may be good enough to use in those situations where less accuracy is acceptable. At any rate, the analytic method should be used in conjunction with the simulation method when the latter method is chosen to insure the simulation results appear valid.

Since two of the four VAB High Bays are used for ET C/O and storage, an increase in the number of VAB High Bays used for Shuttle Vehicle assembly will cause a decrease in the number of ET C/O Cells. This result will create the need for the construction of a separate ET C/O and storage facility.

Table XII. Analytically Derived Launch Enhancement Plan (page 1)

Annual Launch Rate	Simulation Method Results	# Orbiters*	OPF Bays	# MLPs	PSF Bays	ET C/O Cells	VAB High Bays	Launch Pads
13.26	12.95	⁴ (13.26)	2 (2/5) (22.14)	³ (13.75)	1 (2/5) (15.34)	2 (2/5) (35.01)	2 (2/5) (15.79)	2 (2/5) (20.96)
14.19	14.13	⁴ (14.19)	"	³ (17.04)	"	"	2 (3/5) (23.68)	"
15.34	15.35	⁴ (16.55)	2 (3/5) (33.21)	"	"	"	"	"
16.55	15.96	"	"	"	1 (3/5) (23.00)	"	"	"
19.27	18.53	⁴ (19.27)	"	³ (20.62)	"	"	"	2 (3/5) (31.44)
20.62	(4 MLPs) 21.70	⁴ (21.66)	2 (3/7) (46.50)	"	"	"	"	"
23.00	(4 MLPs) 22.65	⁴ (23.07)	"	³ (24.72)	"	"	2 (3/7) (33.15)	"
24.72	---	⁴ (25.99)	"	³ (28.87)	1 (3/7) (32.21)	"	"	2 (3/7) (44.02)
28.87	(4 MLPs) 26.76	⁵ (34.65)	"	"	"	"	"	"

* See last page of table (page 3)

Table XII. Analytically Derived Launch Enhancement Plan (page 2)

Annual Launch Rate	Simulation Method Results	# Orbiters*	OPF Bays	# MLPs	PSF Bays	ET C/O Cells	VAB High Bays	Launch Pads
32.21	-----	"	"	⁴ (38.49)	"	"	"	"
33.15	-----	"	"	"	2 (3/5) (46.01)	"	"	"
34.13	32.68	⁵ ** (34.13)	"	⁴ ** (36.70)	"	2 (2/5)** (38.62)	3 (3/7) (45.87)	"
36.70	33.46	⁶ (42.66)	"	"	"	"	"	"
38.62	37.42	"	"	⁵ (45.87)	"	"	"	"
42.66	-----	"	"	"	"	2 (3/5) (57.94)	"	"
44.02	-----	⁷ (51.19)	"	"	"	"	"	"
45.87	-----	"	"	"	"	"	"	3 (3/7) (66.03)
46.01	43.68	⁷ *** (50.49)	"	⁶ *** (52.80)	"	"	4 (3/7) (57.12)	"

*, **, *** See last page of table (page 3)

Table XII. Analytically Derived Launch Enhancement Plan (last page)

Annual Launch Rate	Simulation Method Results	# Orbiters *	OFF Bays	# MLPs	PSF Bays	ET C/O Cells	VAR High Bays	Launch Pads
50.49	48.46	"	3 (3/7) (69.74)	"	2 (3/7) (64.42)	"	"	"
52.80	-----	8 (58.87)	"	"	"	"	"	"
57.12	-----	"	"	7 (61.60)	"	"	"	"

* Includes one Orbiter for VAFB operations

** Addition of third High Bay for assembly operations reduces the number of ET C/O Cells in the VAB to one. As this single C/O cell can not handle the launch rate, a separate, two cell C/O facility will have to be built. Also, the addition of the third High Bay increased the expected vehicle assembly time. This increase reduced the capacity of the 5 Orbiters from 34.65 to 34.13 launches per year. Similarly, MLP capacity was reduced from 38.49 to 36.70 launches per year.

*** The addition of the fourth High Bay for vehicle assembly increased the expected vehicle assembly time even further. Consequently, the capacity of the 7 Orbiters dropped from 51.19 to 50.49 launches per year, and the capacity of the 5 MLPs dropped from 45.87 to 44.00, forcing the addition of a 6th MLP.

The numbers in the upper row of each cell represent the number of units required and, if applicable, the work shift schedule employed. The lower number in each cell represents the capacity of that facility or piece of hardware. The annual launch rate for a row is set equal to the least of the capacities in that row. The individual capacities are included on the table so that the reader does not have to refer back to tables II through XI to determine which facility or piece of hardware is the choking point in the STS flow.

VI. Application and Analysis

This chapter presents the applications and analyses of the simulation models described in Chapter III. In addition, the results of the sensitivity analysis conducted on the models is presented. The first section describes the results of the sensitivity analysis conducted on the VAFB model and the final results obtained from the model. The methodology used to incorporate the VAFB results into the KSC model is also presented. The second section of this chapter presents the analysis of the KSC model. This section includes the results of the various sensitivity analyses conducted, a sample analysis of the output from the model including a statistical testing of the results, and the final results obtained from the analysis of the KSC simulation model.

VAFB Model Analysis

Sensitivity Analysis. As mentioned in Chapter III, little information was available on which to base the determination of the type of distribution to use for the process times at VAFB. This situation was mainly due to the fact that no actual data exists to compare the times to. For the reasons stated in Chapter III, the normal distribution was selected as the distribution to use for this model. However, two other possible parametric models were considered and sensitivity analysis was conducted to determine how the use of the other models would affect the outcome of the study. The two other methods for modeling the times were, one, to use the uniform distribution, and, two, to use constant times. For the uniform distribution model, the allotted and assessed times from VSTAR 05 were used as the endpoints of the distribution. If the allotted and assessed times were identical, a

constant time was used. In the constant time model, the maximum of the allotted or assessed times was used as the time for the activity. In both of these models, the distributions and the times for ET shipping and Orbiter mission were the same as those in the normal mode. The results from these models is presented in Table XIII.

Table XIII. Three VAFB Distribution Models

Model	Mean Time Between Launches	Standard Deviation	Annual Launch Rate
Normal	32.3551	0.1689	11,281
Uniform	31.8657	0.1374	11,454
Constant	34.3691	0.1171	10,620

These results were tested to determine if there was a significant difference between the launch rates obtained from the three models. Since the normal model was the model selected for use, the other two models were compared to the results of this model. In this test, the null hypothesis is that the means of the two models being tested are equal, while the alternative hypothesis is that the means are not equal. For this test, the assumption is made that the means are normally distributed. The Central Limit Theorem indicates that this assumption is valid for distribution which are the sum of many independent, identically distributed functions (Ref 30). This is the case here. The test statistics and the methodology for applying these tests is that which was presented in Chapter III.

First, the equality of the variances was determined. The statistic that the test statistic was compared to is found in Equation 3 of

Chapter III. If the test statistic was greater than this value, the variances were not considered equal. If the test statistic was less than 4.03, the variances were considered equal. For the normal versus uniform model, the test statistic was $F_o = (0.1689)^2 / (0.1374)^2 = 1.51$ and thus the variances of these two models were considered to be equal. For the normal versus constant model, the test statistic was $F_o = (0.1689)^2 / (0.1171)^2 = 2.03$ and the variances of these two models were also considered to be equal.

Since the variances are equal in these cases, the test statistic to use to test the equality of the means is that of Equation 4 in Chapter III. This test statistic requires the calculation of S_p using Equation 5. The test statistic in this case is compared to the following statistic:

$$t_{\alpha/2, n_1 + n_2 - 2} \quad (39)$$

If the absolute value of the test statistic is greater than the statistic calculated using Equation 39, the means are considered to not be equal; otherwise they are considered to be equal. In these cases, the value for α is 0.05 and $n_1 = n_2 = 10$, and thus the value of the statistic in Equation 39 is 2.101 (Ref 30:600). For the normal versus the uniform model, the value for S_p is 0.1532 and t_o is 7.145. Therefore, there is a significant difference between the two models. For the normal versus the constant model, S_p is 0.1430 and t_o is -31.4926. Therefore, there is also a significant difference between these two models. This analysis reveals that the distribution chosen does indeed have an effect on the outcome of the model. However, the difference in launch rates (Table XII) is not significant from a

practical point of view. Thus the selection of the normal distribution is reasonable and, in fact, results in a mean launch rate that is nearly midway between the launch rates of the other two models. The results are assumed to be more sensitive to the times used in the distribution than to the actual distribution chosen. Therefore, any significant changes in the projected times for the activities modeled could have a greater effect on the outcome.

Model Results. The VAFB model was run with both one and two Orbiters dedicated to the facility. The results of these runs are shown in Table XIII.

Table XIII. VAFB Model Results

Number of Orbiters	Mean Time Between Launches (days)	Average Annual Launch Rate (launches/year)
1	32.3551	11.281
2	19.4117	18.797

Various sources (Refs 31:23; and 33:6) indicate that the average number of launches out of VAFB will be out 10 per year. Thus with the assessed times used in this model, the expected launch rate could be achieved with only one Orbiter, while the maximum rate of 20 per year that was forecast in the initial studies could be nearly reached with two Orbiters dedicated to VAFB use (Ref 21:1).

Since the expected rate of launch from VAFB is 10 per year, it was decided that this value should be used as the annual launch rate for VAFB in the KSC model. It was decided that these launches should be uniformly distributed throughout the year, since this is the

assumption made for the VAFB launches in VSTAR 05.

The distribution used in the KSC model for the processing time of the Orbiter at VAFB was determined simply by using the results of the VAFB model directly. In addition, it was decided not to dedicate an Orbiter to VAFB in the KSC model due to the fact that this would result in the Orbiter remaining idle at VAFB for part of the year when that Orbiter could be put to use at KSC. Therefore, the KSC model allows any of the Orbiters to be launched from VAFB. However, if the launch rate at VAFB increased to 11 or 12 per year, it would be necessary to dedicate at least one Orbiter to VAFB. Additionally, if the processing time for VAFB increases any great amount, then an Orbiter would have to be dedicated to VAFB.

KSC Model Analysis

This section presents the analysis of the KSC simulation model. First, the results of the sensitivity analysis conducted on the distributions, length of each run, number of runs to determine a data point, and the payload mix probabilities are presented. These results are followed by a sample analysis of the output from the model including the statistical testing of the results. Finally, the results of the analysis using the KSC model are presented.

Sensitivity Analysis. The first concern of this analysis, as mentioned in Chapter III, was the degree to which the optimistic and pessimistic times chosen for the beta-PERT distribution affected the results. To analyze this, the model was evaluated under four conditions, with the endpoints for the distribution changed each time. For the first case, the optimistic time was taken as the allotted time and the pessimistic time was set so as to make the distribution symmetric

around the most likely time. In the second case, the pessimistic time was reduced so that the distance between the pessimistic and most likely time was one third the distance between the optimistic and most likely time. The third case returned the value of the pessimistic time to that it originally had and set the optimistic time so that it was one third of its original distance away from the most likely time. Finally, in the last case, the optimistic and pessimistic times were both moved to the one third points used in the preceding two runs. All runs were 3650 days in length and each result was based on 10 repetitions. The results of these runs are presented in Table XIV.

Table XIV. Distribution Changes Results

Case Number	Days Between Launches	Standard Deviation	Annual Launch Rate
1	28.1827	0.5061	12.951
2	25.7959	0.1698	14.146
3	29.8880	0.4821	12.212
4	27.0461	0.1592	13.495

For the test of the variances, the test statistic used is in Equation 1 from Chapter III and this statistic is compared to the value given in Equation 3. The null hypothesis is that the variances are equal, while the alternate hypothesis is that they are not equal. The results of these tests are presented in Table XV.

Table XV. Test on Distribution Cases Variances

Cases Compared	F _o	Results
1 vs 2	8.892	$\sigma_1^2 \neq \sigma_2^2$
1 vs 3	1.102	$\sigma_1^2 = \sigma_3^2$
1 vs 4	10.123	$\sigma_1^2 \neq \sigma_4^2$

The next step was to test the equality of the means. The null hypothesis is that the means are equal, while the alternate hypothesis is that they are not equal. For the cases where the variances were found to be unequal, the test statistic used was that in Equation 8 and this statistic was compared to $t_{\alpha/2, v}$ where v is calculate according to Equation 9. For the case where the variances are considered to be equal, the test statistic is that from Equation 4 with S_p calculated as in Equation 5. This is compared to $t_{\alpha/2, n_1 + n_2 - 2}$. The results of this analysis is presented in Table XVI.

Table XVI. Tests of Distribution Means

Cases Compared	t _o	Results
1 vs 2	14.2283	$\mu_1 \neq \mu_2$
1 vs 3	-7.716	$\mu_1 \neq \mu_3$
1 vs 4	6.776	$\mu_1 \neq \mu_4$

Therefore, the endpoints chosen for the distribution do have an affect on the output of the model in terms of time between launches. However, the calculated launch rates are not drastically different (Table XIV). Thus, there is some possible error due to the endpoints chosen. However, by using the endpoints chosen in the parametric model, the overall model allowed for both unexpected delays and time reductions in activities. This fact, along with the reasons cited in Chapter III, resulted in the choice of the endpoints in case 1 for use in the model.

Next, it needed to be determined whether or not the length of the runs (3650 days) was adequate to characterize the mean time between launches. To test this length, the model was run for both 3650 and 7300 days. The results of these runs are presented in Table XVII.

Table XVII. Run Results

Length of Run	Time Between Launches	Standard Deviation
3650 days	28.1827	0.5061
7300 days	28.2833	0.2598

First, the equality of the variances was checked using the formulas in Equations 1 and 3. In this case, $F_0 = 3.794$ which is less than 4.03 and thus the variances are considered equal. The means are compared using Equation 4 for the test statistic and $t_{\alpha/2, n_1 + n_2 - 2}$ for the comparison statistic. To calculate t_0 , S_p must first be calculated using Equation 5. For this example, $S_p = 0.38295$ and $t_0 = -0.587$. The absolute value of t is less than $t_{0.025, 10}$ or 2.101. Therefore, the means are not significantly different and 3650

days is an adequate run length for characterizing the mean time between launches.

The next area that required testing was that of the number of runs required to adequately characterize the mean. For this analysis, three different values for the number of runs were examined; these being 5 runs, 10 runs, and 50 runs. Each run was 3650 days in length as determined before. The results of these different cases are presented in Table XVIII.

Table XVIII. Number of Runs

Number of Runs	Time Between Launches	Standard Deviation
5	28.1008	0.5919
10	28.1827	0.5061
50	28.2596	0.4152

The variances and means were tested as in previous analyses. The results are presented in Tables XIX and XX.

Table XIX. Test on Run Variances

Runs Compared	F ₀	Result
10 vs 5	1.368	$\sigma_{10}^2 = \sigma_5^2$
10 vs 50	2.400	$\sigma_{10}^2 = \sigma_{50}^2$

Table XX. Test on Run Means

Cases Compared	t_o	Result
10 vs 5	0.2800	$u_{10} = u_5$
10 vs 50	-0.5155	$u_{10} = u_{50}$

Therefore, there is no statistically significant difference between 5, 10, and 50 runs of the system. They all characterize the mean well. Ten runs was chosen for the model since fewer runs would decrease our confidence in the results, and more runs would have increased the computer time required to complete a simulation run.

Finally, the probabilities that were selected to determine the type of payload to be placed in the Orbiter were examined for their affect on the results. There are two places in the model where the payload type could affect the turnaround time. They are the OFF payload activities and the mission flight times. In the OFF, horizontal and Spacelab payloads (types 1 and 2) require more processing time - then do the verticle payloads (type 3) which are loaded at the pad. This difference is expected to have little effect though, since regardless of the payload type, the same maintenance activities are performed. The mission duration, however, could affect turnaround. The Spacelab mission has an average duration of 12 days, while the other missions have an average duration of only 4 days. Therefore, significant increases in the number of Spacelab missions could increase the turnaround time for the Orbiters. To test the

sensitivity of the model to the payload types the following payload variations were tested (Table XXI).

Table XXI. Payload Types and Probabilities

Payload Case	Payload Type 1 Probability	Payload Type 2 Probability	Payload Type 3 Probability
1	0.172	0.345	0.483
2	0.1	0.4	0.5
3	0.2	0.1	0.7
4	0.3	0.2	0.5
5	0.5	0.1	0.4

The results from each of these cases is presented in Table XXII.

Table XXII. Payload Type Tests

Payload Case	Days Between Launches	Standard Deviation
1	28.1827	0.5061
2	28.1101	0.3559
3	28.2174	0.2070
4	28.5976	0.2476
5	28.5791	0.2779

These results were tested using the same methodology given in the previous analysis. The results of these tests are contained in Tables XXIII and XXIV.

Table XXIII. Test of Payload Variances

Payload Case	F _o	Results
1 vs 2	2.022	$\sigma_1^2 = \sigma_2^2$
1 vs 3	5.978	$\sigma_1^2 \neq \sigma_3^2$
1 vs 4	4.178	$\sigma_1^2 \neq \sigma_4^2$
1 vs 5	3.317	$\sigma_1^2 = \sigma_5^2$

Table XXIV. Test of Payload Means

Payload Case	t _o	Results
1 vs 2	0.377	$u_1 = u_2$
1 vs 3	-0.201	$u_1 = u_3$
1 vs 4	-2.329	$u_1 \neq u_4$
1 vs 5	-2.261	$u_1 \neq u_5$

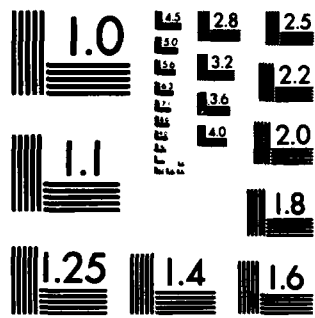
The above results indicate that as the percent of Spacelab payloads increases, the greater is the effect on the model results. However, no effect was significant until the Spacelab made up 30 percent of the total payloads. A review of the current flight manifest indicates that the probability of Spacelab use being this high is low, and therefore this concern is not a major one (Ref 9).

Sample Analysis and Results. The following is a step by step analysis of the output from the Q-GERT model. The output from the starting configuration is used for this example. The sample output used can be found in Figures 4 and 5. The calculations shown are representative of the calculations used throughout the analysis.

The first step is to determine the launch rate that the current configuration is capable of achieving. This is accomplished by using the average value (column headed by AVE.) for node 40, LAUNCH. This number is the average time between launches, which in this case is 28.1827 days. The launch rate is found by dividing this number into 365 days per year. This calculation yields a launch rate of 12.951 launches per year.

Once the launch rate has been calculated, the next step is to determine the factor(s) that is/are limiting the launch rate. This job is done by first looking at the Average Resource Utilization and Availability tables of the output (Figures 4 and 5). These tables indicate that the PSF, VAB, ET Barge, ET checkout cell, ET storage cell, and the SRB storage are all in nearly constant use. The fact that the SRB storage and the ET storage cells are nearly full indicates that the functions filling these cells are producing above the level required and as such they are not the limiting factors. This step eliminates the ET production and the PSF from consideration as limiting factors. This step also indicated that the VAB may be a limiting factor.

The next area of the output to examine is the queue node statistics. The data in the queue table can be used to determine where items are waiting in queues and the length of time that they are required to wait. The following nodes are of the most interest for this analysis:



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

FINAL RESULTS FOR 10 SIMULATIONS

AVERAGE NODE STATISTICS

NODE	LABEL	PROBABILITY	AVE.	STD.DEV.	SD OF AVE	NO OF	MIN.	MAX.	STAT
						REPS.			TYPE
76	RETRY'S 0	1.0000	28.2613	.5171	.1635	10.	27.4231	29.1229	0
90	RETRYAB	1.0000	28.2340	.4774	.1510	10.	27.4607	29.0573	0
97	RETRYBST	1.0000	28.2451	.5293	.1674	10.	27.3481	29.1077	0
95	RETRYABE	1.0000	36.5655	.3030	.0000	10.	36.5655	36.5655	0
93	RETRYCO	1.0000	28.2427	.5246	.1659	10.	27.4231	29.1229	0
84	RETRYBM	1.0000	29.1818	.5206	.1646	10.	27.4231	29.1229	0
62	RETRYSF	1.0000	28.2324	.5274	.1668	10.	27.3577	29.1077	0
58	RETRYTIE	1.0000	36.3709	.2023	.0640	10.	35.9737	36.6069	0
42	RETRYAD	1.0000	28.2036	.5082	.1607	10.	27.3931	28.9752	0
98	LAUNCH	1.0000	28.1827	.5061	.1608	10.	27.3931	28.9752	0
39	RETRYL	1.0000	28.2379	.5013	.1527	10.	27.4607	29.0573	0
25	OPRTIME	1.0000	35.7358	.5924	.0893	10.	35.259	36.1407	1

AVERAGE NUMBER IN Q-NODE

NODE	LABEL	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.	AVE.	STD.DEV.	SD OF AVE	NUMBER IN Q-NODE
2	WAITOP	.7922	.0029	.0029	.0024	.1104	2.6094	.2748	.0889	2.0070
11	WAITMAIN	.0901	.0042	.0042	.0611	.1039	2.2532	.3668	.1097	2.0070
12	WAITPASS	.0056	.0007	.0007	.0030	.0104	1.5980	.0642	.0203	2.0070
10	WAITSSPE	.4327	.0064	.0064	.4006	.4909	12.1688	.6951	.1914	2.0070
17	SSMETH	.3164	.0043	.0043	.2586	.3556	8.9003	.6901	.2142	2.0070
18	WAITPASS	.0044	.0014	.0014	0.0000	.0138	1.1231	.1549	.0395	1.0071
20	WAITSCH	.7582	.0080	.0080	.7207	.8028	21.7163	.6119	.1925	2.0060
23	SCHWALT	.1847	.0042	.0042	.1670	.2060	5.2002	.4105	.1298	2.0060
27	OPRWAIT	.2632	.0045	.0045	.2427	.2948	13.9213	.3967	.0774	2.0060
32	OPRWAIT	.7003	.0016	.0016	.6900	.7051	7.4110	.6030	.1907	1.0060
36	WAITPAD	.0122	.0016	.0016	.0057	.0176	1.4939	.0887	.0437	1.0060
49	WFRWAIT	.0502	.0121	.0121	.0156	.1423	1.9232	1.3000	.4364	2.0060
52	WAITSP	4.3991	.0110	.0110	4.3901	4.8419	125.4668	2.3694	.7493	7.0060
55	WAITSRM	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0060
54	WAITPFS	4.4239	.0119	.0119	4.3642	4.86670	126.1715	2.3709	.7497	7.0060
58	WAITSTR	1.5677	.0054	.0054	1.227	1.822	4.9281	.6697	.2119	1.0060
63	WAITMLP	1.4464	.0093	.0093	1.4004	1.4494	51.5593	1.4442	.4453	2.0060
65	WAITVAR	1.332	.0045	.0045	1.016	1.740	3.5970	.6322	.1999	1.0060
67	WAITSPR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0060
72	WAITET	0.0000	0.0000	0.0000	0.0000	0.0700	0.7000	0.0000	0.0000	0.0060
74	WAITORM	.0429	.0179	.0179	.0511	.1137	2.3464	.5231	.1534	2.0060
91	WAITRAB	2.7794	1.0037	1.0037	.9977	7.0571	77.5720	47.6331	15.6956	14.0060
90	WAITRAB	2.7916	.0769	.0769	2.2277	3.4924	82.4157	12.0798	3.9200	4.0060
89	WAITRST	1.2393	.0399	.0399	1.1945	1.2944	34.7668	1.6465	.5207	2.0060
74	WAITRSM	1.3470	.0713	.0713	1.0145	2.0000	55.5275	1.6720	.5104	2.0060

Figure 4. Sample Output A

CRITICAL VALUES									
SERVER	LABEL	NO. PARALLEL	AVE.	STD.DEV.	SD OF AVE	NO. OF	MIN.	MAX.	MAX. BUSY
		SERVS				CMS.		(TIME OR SEVRS)	
06	LANDOOPS	1	.0032	.0001	.0000	10.	.0031	.0033	185.1549
07	VLANDOOPS	1	.0025	.0000	.0000	10.	.0025	.0025	85.2186
08	VMPROPS	1	.0085	.0052	.0016	10.	.0328	.1637	54.0851
23		1	0.0000	0.0000	0.0000	10.	0.0000	0.0000	199.3582
35	BUILDUP	1	.0186	.0211	.0067	10.	.0788	.4519	70.5942
43		1	0.0000	0.0000	0.0000	10.	0.0000	0.0000	36.4866
55		1	0.0000	0.0000	0.0000	10.	0.0000	0.0000	53.4126
							0.0000	0.0000	56.3015
									0.0000

AVERAGE SEVRS UTILIZATION									
NODE	LABEL	AVE.	STD.DEV.	SD OF AVE	NO. OF	MIN.	MAX.		
					CMS.				
05	LANDMISC	.0007	.0001	.0000	10.	0.0000	.0003		
07	VMPRLAND	0.0000	0.0000	0.0000	10.	0.0000	0.0000		

AVERAGE RESOURCE UTILIZATION									
RESOURCE	LABEL	AVE.	STD.DEV.	SD OF AVE	NO. OF	MIN.	MAX.		
					CMS.			NUMBER OF RESOURCES	
1	OPFRAY	1.5299	.0330	.0104	10.	1.4915	1.5668	2.	
2	CRAWLER	.0533	.0052	.0016	10.	.0492	.0633	1.	
3	PAD	1.2120	.0277	.0099	10.	1.1510	1.2422	2.	
4	P-F	1.0000	.0000	.0000	10.	1.0000	1.0000	1.	
5	SRMSTOPE	1.8044	.0295	.0093	10.	1.8036	1.8088	2.	
6	VAB	1.7073	.0176	.0056	10.	1.6799	1.7295	2.	
7	MSCBA:GE	3.4935	.4016	.1270	10.	2.8738	3.9752	4.	
8	ETICCELL	1.9862	.0220	.0069	10.	1.9765	2.0000	2.	
9	CYSTORE	1.9458	.0018	.0006	10.	1.9396	2.0000	2.	

AVERAGE RESOURCE AVAILABILITY									
RESOURCE	LABEL	AVE.	STD.DEV.	SD OF AVE	NO. OF	MIN.	MAX.		
					CMS.			NUMBER OF RESOURCES	
1	OPFRAY	.4781	.0330	.0104	10.	.4332	.5185	2.	
2	CRAWLER	.9447	.0032	.0016	10.	.9367	.9509	1.	
3	PAD	.9400	.0277	.0099	10.	.8795	.9430	2.	
4	P-F	0.0000	0.0000	0.0000	10.	0.0000	0.0000	1.	
5	SRMSTOPE	.1514	.0295	.0093	10.	.1112	.1906	2.	
6	VAB	.2927	.0176	.0056	10.	.2795	.3241	1.	
7	MSCBA:GE	.5045	.4016	.1270	10.	.0244	1.2620	4.	
8	ETICCELL	.2139	.0220	.0069	10.	0.0000	.0535	2.	
9	CYSTORE	.0640	.0018	.0006	10.	0.0000	.0030	1.	

Figure 5. Sample Output B

1. Node 2, WAITOPF - Orbiters wait in this node for an OPF bay;
2. Node 27, ORBWAIT - Orbiter waits for SRB/ET assembly after finishing processing in the OPF;
3. Node 78, WAITORB - the ET/SRB assembly waits for an Orbiter to finish OPF processing;
4. Node 58, WAITSTOR - SRB set waits for SRB storage cell;
5. Node 63, WAITMLP - SRB set waits in storage for MLP/VAB High Bay to become available;
6. Node 68, WAITSRB - the MLP/VAB waits for an SRB set;
7. Node 65, WAITVAB - the MLP waits for a VAB High Bay;
8. Node 72, WAITET - the stacked SRB waits for an ET; and
9. Node 94, WAITSRB - the ET waits for the stacked SRB set.

The two columns of primary interest in this section of the output are the average number in the queue node and the average waiting time in the queue. The average waiting time is calculated based only on the transactions that actually have to wait.

The best method of analysis of the queue data is to compare the data for queue nodes that proceed an assembly operation. As a starting point, the data on the Orbiter waiting to be mated (node 27) and the data on the ET/SRB assembly (node 78) are compared. The information in the output indicates that there is a larger average number of Orbiters waiting (0.2632) as compared with the average number of SRB/ET assemblies (0.0829). In addition, the Orbiters wait longer (7.4110 versus 2.3464 days) than the SRB/ET assemblies. These results indicate that neither the OPF nor the Orbiters are the limiting factor, but that the delay is occurring prior to the SRB/ET mating operation. The first assembly point prior to the SRB/ET mate indicated that the SRB is not waiting for ETs

(node 72). The ETs on the other hand wait in storage an average of 55.6275 days (node 94). This time appears excessive. However, it is primarily due to a slight over production of ETs.

The next point where components wait for assembly is prior to the SRB stacking. The queues before this point indicate that there is an average of 1.8484 SRBs waiting (node 63) while the MLP/VAB never have to wait for an SRB set. This difference indicates, as did the resource data, that the PSF is processing an adequate number of SRPs and it is not the limiting factor.

The analysis so far has narrowed the limiting factor down to either the MLP or the VAB. The data for queue node 65 indicates that there is an average of 0.1302 MLPs waiting an average of 3.6870 days each for a VAB bay to become available. This leads to the result that the VABs are the limiting factor. This fact agrees with the data in the resource tables discussed previously. Keeping in line with the philosophy stated in Chapter III, shifts are added to the VABs before a new VAB High Bay is added. At this point, the work shifts in the VAB were increased from two shifts for five days per week to three shifts per five days per week. The model was then rerun and the result was an average time between launches of 25.8320 days and a launch rate of 14.129 launches per year. To determine if this is a statistically significant increase in the launch rate, the statistical tests described in Chapter III were accomplished. The sample calculations for these tests is presented in the following paragraphs.

The average time between launches for the first run was 28.1827 days and the standard deviation was 0.5061. For run two, the average time between launches was 25.8320 days and the standard deviation was

0.2060 days. The first step was to test the equality of the variances. F_0 was found to be 6.036. This is larger than the comparison statistic (4.03) and therefore the null hypothesis is rejected and the variances are assumed to be not equal.

Next, the null hypothesis of $u_1 = u_2$ was tested against the alternate hypothesis that $u_1 > u_2$. The test statistic in this case was found to be 13.598. The comparison statistic is $t_{\alpha, v}$ where $v = 12,548$. Therefore, the value of the comparison statistic is 1.771 (Ref 30:596) at $\alpha = 0.05$. Since t_0 is greater than the comparison statistic, the null hypothesis is rejected and the time between launches for the first run is assumed to be greater than that of the second run. This leads to the conclusion that the launch rate of the second run is greater than that of the first run.

At this point, the output of the second run was analyzed to determine the limiting factor. This process was continued until the desired launch rate was achieved. The results are presented in Table XXV. The results in this table show the facility additions that this study recommends and the order in which they should be added to efficiently increase the launch rate. There were some instances where the analysis of the output indicated that there were two or more limiting factors occurring at the same time. In these cases, each of the limiting factors were increased individually to determine which factor increase would result in the greatest increase in launch rate. A table presenting all of the configurations examined can be found in Appendix A.

Table XXV. Simulation Derived Launch Enhancement Plan

Annual Launch Rate	# Orbiters*	OFF Bays	# MLPs	PSP Bays	ET C/O Cells	VAB Hg Bays	Launch Pads
12.95	4	2 (2/5)	3	1 (2/5)	2 (2/5)	2 (2/5)	2 (2/5)
14.13	"	"	"	"	"	2 (3/5)	"
15.35	"	2 (3/5)	"	"	"	"	"
15.96	"	"	"	1 (3/5)	"	"	"
18.53	"	"	"	"	"	"	2 (3/5)
21.70	"	2 (3/7)	4	"	"	"	"
22.65	"	"	"	"	"	2 (3/7)	"
24.04	"	"	"	1 (3/7)	"	"	"
26.76	"	"	"	"	"	"	2 (3/7)
30.06	5	"	"	"	2 (3/5)	"	"
31.34	"	"	"	"	2 (3/7)*	3 (3/7)	"
32.68	"	"	"	2 (3/7)	"	"	"
33.46	6	"	"	"	"	"	"
37.42	"	"	5	"	"	"	"
38.95	"	"	"	"	"	4 (3/7)	"
40.20	"	3 (3/7)	"	"	"	"	"
41.64	"	"	6	"	"	"	"
43.68	7	"	"	"	"	"	"
48.46	"	"	"	"	"	"	3 (3/7)

* Includes one Orbiter for VAFB operations

** The addition of the third High Bay for vehicle assembly reduces the number of ET C/O Cells in the VAB to one. As this single cell can not handle the launch rate, a separate, two cell ET C/O and storage facility will have to be built.

See the next page for additional comments on this plan.

Additional comments on the Enhancement Plan:

1. The PSF has two storage bays in addition to the single processing bay. The addition of a second PSF is required when the launch rate reaches 30.06 launches per year. This second facility was run with a single processing bay and three storage bays. The total of the two PSF facilities is then two processing bays and five storage bays.
2. ET and SRB production rates are assumed to match the annual launch rate. This annual launch rate includes the rate for KSC and that for VAFB (assumed to be 10 per year). Therefore, it should be increased to 40 per year when KSC reaches 14 per year, and to 60 per year when KSC reaches 30 launches per year.
3. The simulation results showed that a single crawler (of the two available) was sufficient to handle all the launch rates examined. In addition, four barges able to handle a single ET each were found to be able to handle all of the launch rates examined. The model assumed that there was an additional, four ET barge available to transport ETs to VAFB.
4. The model also assumed that there were as many ET storage cells as there were C/O cells.

VII. Conclusions

The Space Transportation System is being developed to launch NASA, DoD, and commercial payloads. National policy directs NASA and DoD to use the STS as their primary means for launching payloads into earth orbit. Consequently, most DoD payloads will be launched by the STS, and DoD's share of STS flights will rise to 50% after 1988. Scheduled DoD payloads include missile warning, surveillance, communication, navigational, and meteorological satellites (Refs 1; and 2). Future payloads may include space based defensive weapon systems (Refs 3:15; 4:41).

Unfortunately, STS launch capacity is already saturated, and the flight hardware procurement and launch processing facility construction needed to increase the system launch rate are not contained in current funding plans (Refs 5:20; and 6:16-17). Those funds which may later become available must be wisely spent to insure that the launch rate is increased to the level needed to meet critical national defense needs. Therefore, they must be spent on those portions of the system which contribute greatest to increasing the system launch rate.

The purpose of this thesis effort was to develop a plan for increasing the STS launch rate. The problem was to develop a method to accurately predict STS launch rate capability given various facility configurations and flight hardware levels. Two such methods were developed; one uses an analytic approach, while the other uses a simulation approach. The analytic approach in Chapter V turned out to be surprisingly useful. However, it does not accurately reflect the complex interactions which occur as flight hardware progresses through the launch processing facilities. The simulation approach

uses Q-GERT modeling techniques to properly reflect the flow of flight hardware through the various facilities, and the complex interactions which result. Both methods properly identified the bottlenecks in the STS and were used to develop plans for sequentially adding capacity at bottlenecks in order to efficiently increase the system launch rate. These plans are based on the assumption that work shifts will be added at the processing facilities before the facilities are expanded or additional flight hardware is procured.

The times it takes to complete the various processing activities were obtained from the Space Shuttle Turnaround Analysis Report (STAR 23) (Ref 12). Only five STS launches have taken place to date, and the processing activities are still high on their learning curves. Consequently, the available samples of activity times are not adequate for use in determining their ultimate statistical distributions. Therefore, the assessed activity times given in the STAR are the best available estimates of the times to be achieved once the system matures. These times were used as the average activity times in the analytic approach and as the most likely times for the distributions used in the simulation approach.

Analytic vs Simulation

The analytic method is based on a simple network flow diagram which reflects the capacities of the major facilities and hardware in the STS. The Q-GERT simulation approach breaks down the STS into the activities which take place within each of the facilities. Statistical distributions were developed for these activities and used by the Q-GERT computer routines to simulate the operation of the real system. The Q-GERT structure developed takes into account the blockages which

can occur as a result of the limited capacities of the various facilities. The number of simulation runs to make for each system configuration, and the length of each of these runs were set at the levels needed to accurately estimate the mean predicted launch rate and to adequately characterize its distribution. The design of the simulation method and its application are presented in Chapters III and VI, while the verification and validation of this method are presented in Chapters IV and V. The analytic method presented in Chapter V was developed for use in validating the results of the simulation method. The analytic results were compared to the simulation results to insure that the latter have the appearance of validity. The closeness to which the results of the two methods match greatly increases the confidence with which the simulation method and the launch enhancement plan can be used. As more STS launches take place, and as more accurate estimates of STS activity times become available, the two methods can be used to update the launch enhancement plan presented in Table XXV.

For many purposes, the analytic method may adequately predict the system launch rate. It offers some advantages over the simulation method, for it can be relatively quickly done, and it does not require a knowledge of Q-GERT techniques, access to a Q-GERT simulation package, or the use of computer resources. By comparing the analytic and simulation plans presented in Tables XII and XXV, it can be seen that the analytic method consistently overstates STS launch rate capability by up to three launches per year. The simulation method should be used when this degree of error is considered significant. In the latter case, the analytic method is still useful, for it can be used to help validate the simulation results, and to provide a guide to use in

choosing the facility/hardware configurations to test with the simulation method.

In summary, both the analytic and the simulation methods are useful ways to predict STS launch rate capability. The predicted capabilities for various system configurations and hardware levels can then be used to develop a launch enhancement plan which would apply scarce funds to those portions of the system which contribute greatest to increasing the system launch rate. The simulation method is more accurate than the analytic method, but it takes more time, knowledge, and material resources to do. Therefore, the degree of accuracy desired will dictate which method to use.

Launch Enhancement Plan

The results of the analytic and simulation methods are presented in the launch enhancement plan shown in Table XXV. This plan applies to the facilities at KSC. Although the simulation method was used to determine the launch rate capability of VAFB, no plan was developed to increase the VAFB launch rate. All SRB/ET stacking, Orbiter mating, and payload operations are done on the launch pad at VAFB. Therefore, any plans to increase that site's capability would have to include duplication of most of the VAFB facilities.

The analytic and simulation methods both produced nearly the same sequence of facility configurations and hardware levels. In addition, the system launch rate capabilities predicted by the two methods closely matched. Since the simulation results were more accurate than the analytic results, the launch enhancement plan shown in Table XXV is the one we recommend for use. However, the simulation method did not directly provide the capacity of each of the facilities

and hardware items at each step in the sequence. If these individual capacities are of interest, their analytic estimates are shown in Table XII. To use either plan, look for the desired launch rate in the left hand column. The facility configurations and hardware levels listed to the right of that number are the ones required to meet that launch rate. The numbers within each block give the number of units needed and, if appropriate, the work week schedule required.

It should be noted that the listed launch rates do not take into account work interruptions caused by holidays or accidents. Users may consider adding additional launch rate capacity to allow for these interruptions. Also, it should be cautioned that the data this plan is based on is undergoing periodic revision. Consequently, the plan presented may quickly become outdated. Therefore, the methods presented in this thesis should be used on the new data provided in future STARS to produce updated versions of the plan. Finally, it is left to DoD and NASA management to balance the costs associated with achieving a particular launch rate against the value of the payloads and budgetary constraints.

VIII. Recommendations

We have the following recommendations for follow on efforts to make.

Eventually, sufficient actual launch processing data will be accrued to permit accurate fits of probability distributions to. We recommend that the thesis effort be repeated using these distributions in place of the beta-PERT distributions assumed this time around. If the analytic method is also used on this actual data, care must be taken to insure that the analytic capacities are calculated using the mean activity times and not their most likely values. It may also be useful to periodically repeat this effort using the estimated times given in new STARS until the actual times are readily available.

Finally, no allowances were made for interruptions caused by accidents. We recommend that a study be done to determine the proper allowance to make. The study could be based on the actual STS accident rate once the system matures, or, until then, on similar experiences with other systems. The determined allowance could be included as a figure to add to the desired launch rate, or it could be included probabilistically in the analytic and simulation methods themselves.

If carried out, these recommendations will insure that the launch enhancement plan is kept up to date, and that proper allowance will be made for capacity reductions caused by accidents.

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Appendix A

KSC Q-GERT Model and Results

This appendix contains the KSC Q-GERT simulation model used in this thesis. The graphical model is presented in Figure 6 and is followed by the listing of the computer program used in the analysis and the parameters used in the model (Tables XXVI, XXVII, and XXVIII). Finally, the full set of results is presented in Table XXIV.

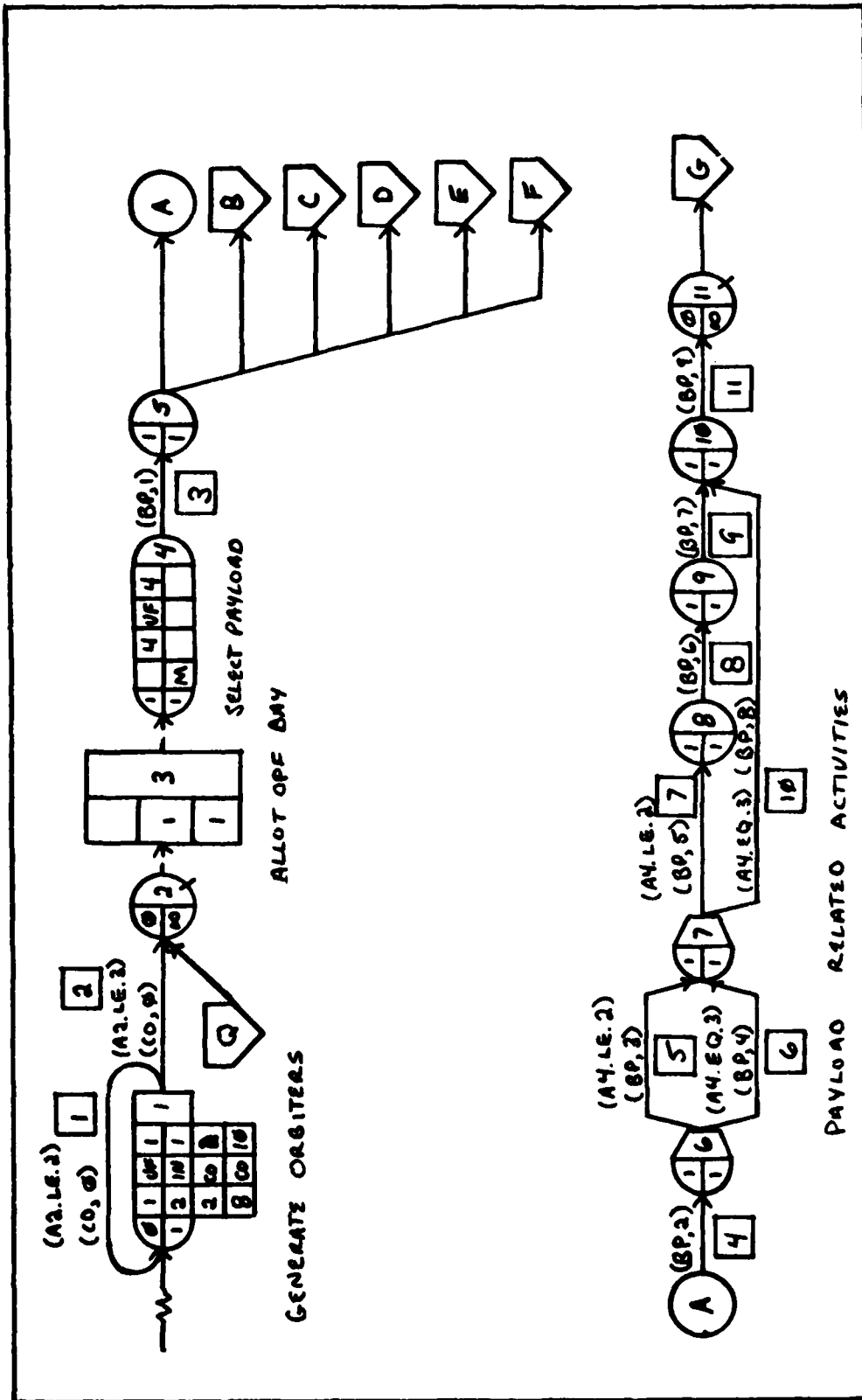


Figure 6. KSC Q-CERT Graphical Model (Page 1 of 7)

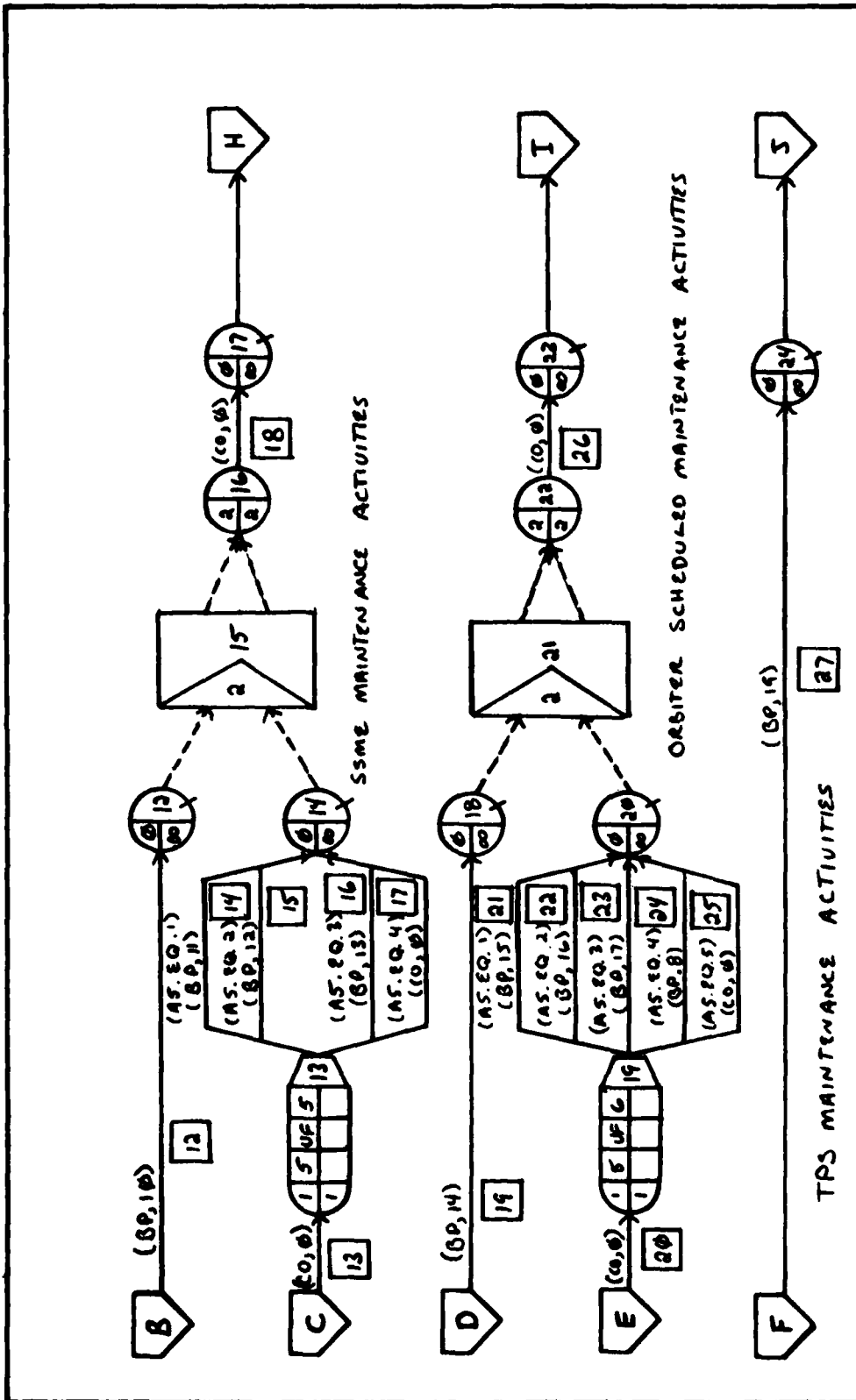


Figure 6. KSC 3-GERT Graphical Model (Page 2 of 7)

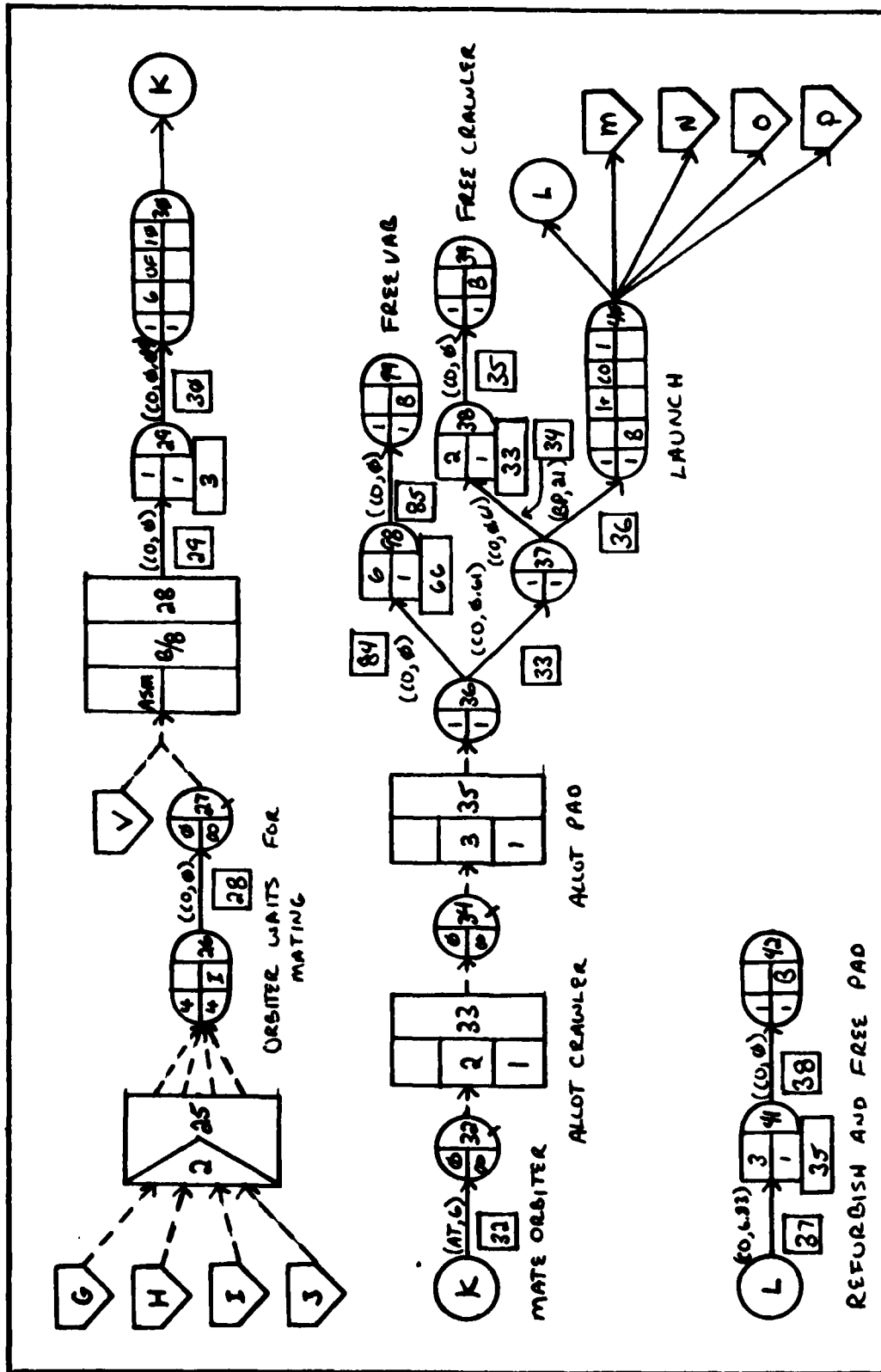


Figure 6. KCC Q-GERT Graphical Model (Page 3 of 7)

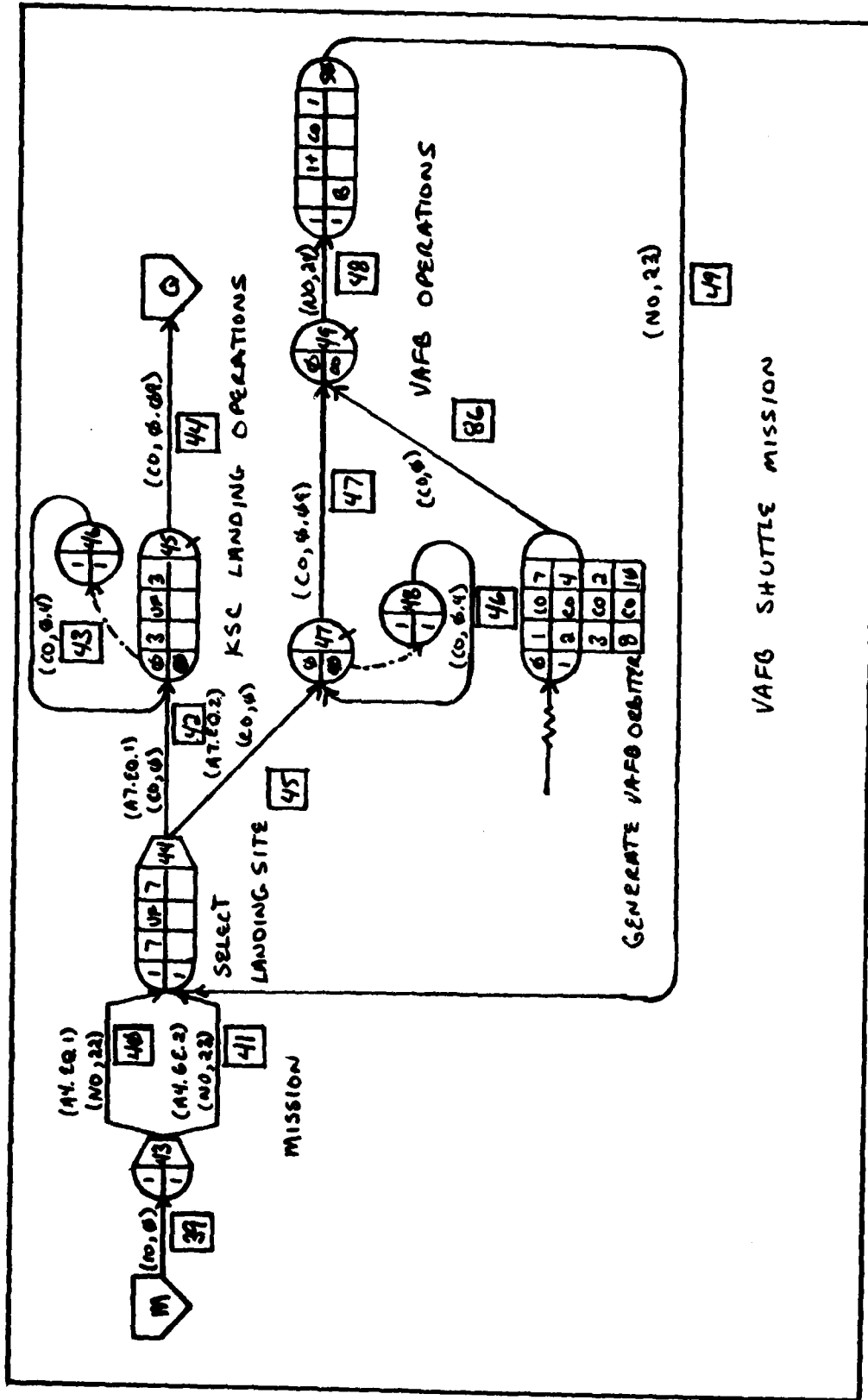


Figure 6. KSC Q-CERT Graphical Model (Page 4 of 7)

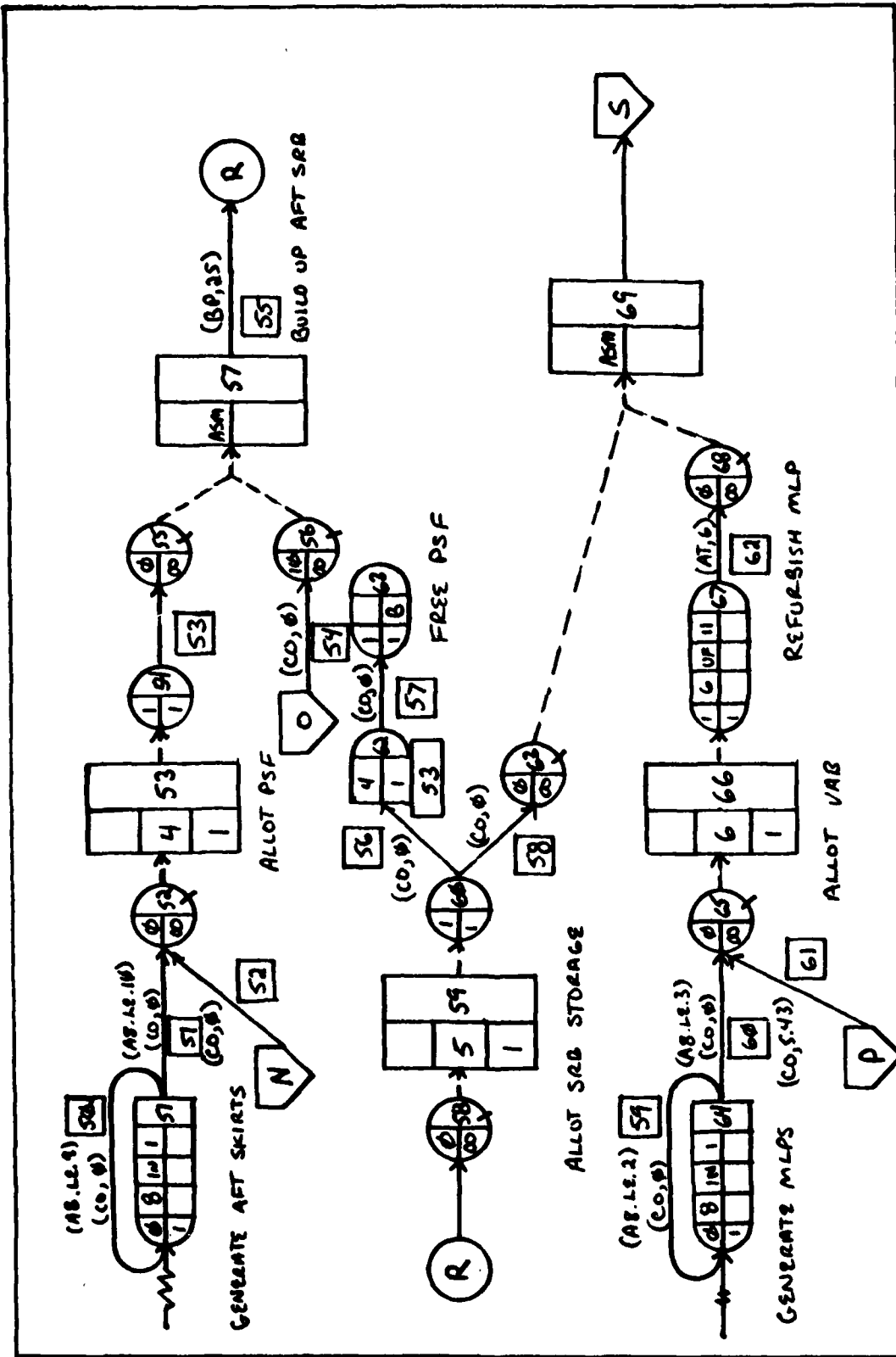


Figure 6. H30 2-STEP Graphical Model (Page 5 of 7)

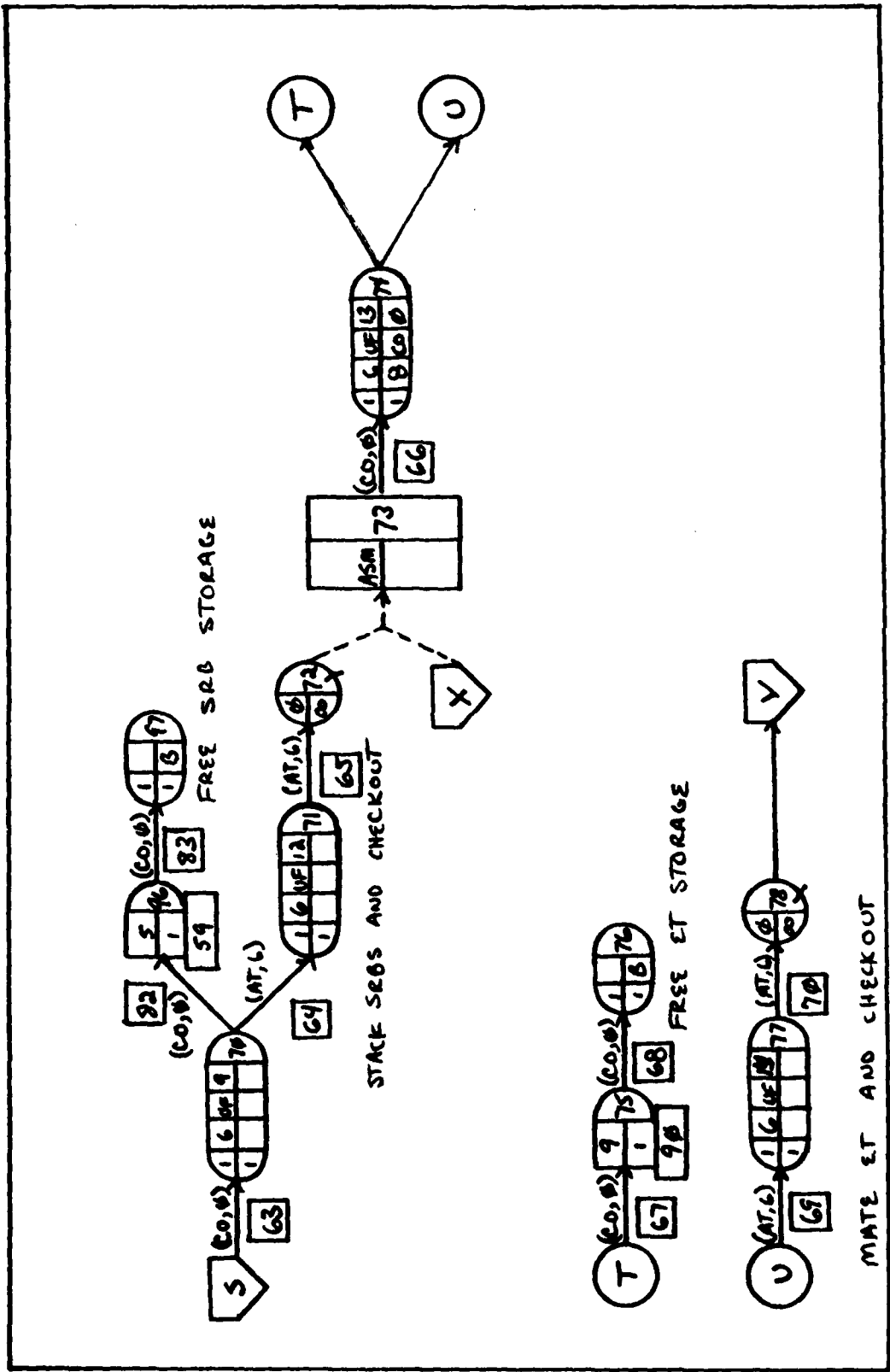


Figure 6. KSC Q-GERT Graphical Model (Page 6 of 7)

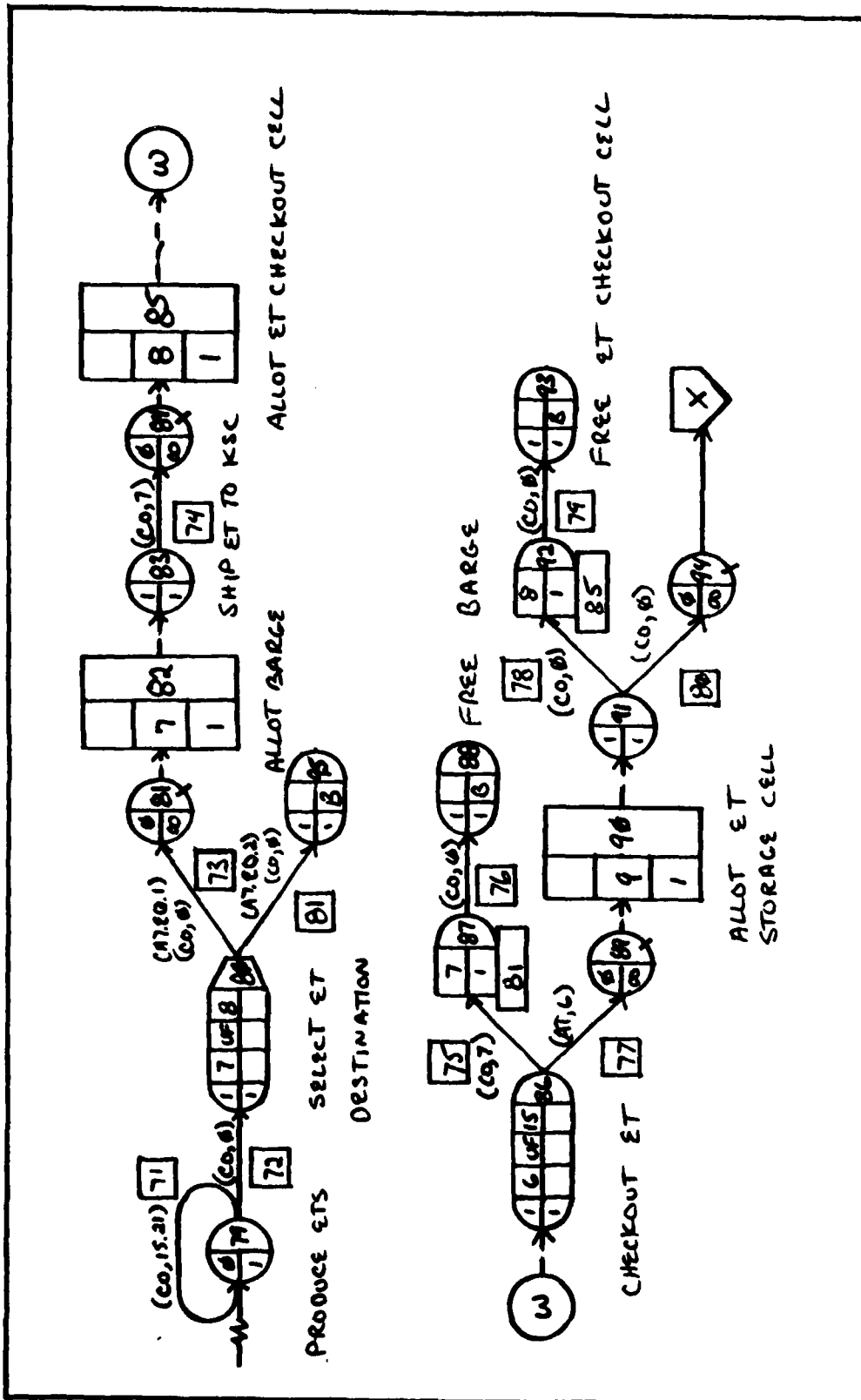


Figure 6. KSC Q-GERT Graphical Model (Page 7 of 7)

```

*****
* THIS PROGRAM IS THE O-GERT CODE FOR A SIMULATION MODEL THAT *
* DEPICTS THE FLOW OF THE SPACE TRANSPORTATION SYSTEM (STS) *
* AT THE KENNEDY SPACE CENTER (KSC). THIS MODEL IS USED TO *
* PREDICT THE LAUNCH RATE CAPABILITY OF THE STS. THE CODE *
* CAN BE CHANGED TO MODEL VARIOUS CONFIGURATIONS OF THE FAC- *
* ILITIES, HARDWARE, AND WORK SCHEDULES TO DETERMINE HOW EACH *
* CONFIGURATION AFFECTS THE LAUNCH RATE. SPECIFIC METHODS OF *
* ALTERING THE MODEL ARE DESCRIBED IN COMMENTS FURTHER ON IN *
* THIS PROGRAM. THE RESOURCES THAT ARE READILY AVAILABLE FOR *
* ALTERATION ARE:
*
* 1. NUMBER OF ORBITERS;
* 2. NUMBER OF ORBITER PROCESSING FACILITIES (OPF);
* 3. NUMBER OF CRAWLERS (TO TRANSPORT STS TO PAD);
* 4. NUMBER OF PADS;
* 5. NUMBER OF VEHICLE ASSEMBLY BUILDING (VAB) BAYS;
* 6. NUMBER OF MOBILE LAUNCH PADS (MLP);
* 7. NUMBER OF SOLID ROCKET BOOSTER (SRB) PROCESSING
* AND STORAGE FACILITIES (PSF);
* 8. NUMBER OF SRB STORAGE BAYS;
* 9. NUMBER OF EXTERNAL TANKS (ET) PRODUCED PER YEAR;
* 10. NUMBER OF ET BARGES (TO SHIP FT TO KSC);
* 11. NUMBER OF ET CHECKOUT CELLS;
* 12. NUMBER OF ET STORAGE CELLS; AND
* 13. NUMBER OF WORK SHIFTS PER WEEK.
*
* NOTE: THIS MODEL ASSUMES THAT THE SRB REFURBISHMENT AND
* PRODUCTION RATE CAN BE SCHEDULED AND BALANCED TO
* BE ABLE TO PROVIDE THE NUMBER OF SRB PAIRS REQUIRED
* TO MEET THE LAUNCH RATE. THE MODEL DOES HOWEVER
* CONSIDER THE AFT BUILD UP OF THE SRB.
*
* THIS PROGRAM PROVIDES AS OUTPUT A SUMMARY OF ALL OF THE
* RUNS OF THE SYSTEM. THE SUMMARY INCLUDES THE FOLLOWING:
*
* 1. A LISTING OF THE STATISTICS COLLECTED AT EACH
* DESIGNATED NODE TO INCLUDE:
*
* A. THE AVERAGE TIME BETWEEN LAUNCHES (IN DAYS,
* NODE 40 LAUNCH);
*
* B. THE STANDARD DEVIATION OF THE AVERAGE;
*
* C. THE AVERAGE OF THE STANDARD DEVIATION; AND
*
* D. THE NUMBER OF RUNS OF THE MODEL;
*
* 2. A LISTING OF DATA ON THE QUEUE NODES TO INCLUDE:
*
* A. NODE NUMBER AND LABEL;
*
* B. AVERAGE NUMBER IN THE QUEUE NODE WITH
* STANDARD DEVIATION; AND
*
* C. AVERAGE WAITING TIME IN THE QUEUE WITH
* STANDARD DEVIATION; AND
*
* 3. A LISTING OF RESOURCE AVAILABILITY AND UTIL-
* IZATION.
*
* THE NODE 40 STATISTICS CAN BE USED TO DETERMINE THE LAUNCH
* RATE CAPABILITIES BY DIVIDING THE NUMBER OF DAYS IN A YEAR
* (365) BY THE AVERAGE NUMBER OF DAYS BETWEEN LAUNCHES. THIS
* GIVES A RESULT IN LAUNCHES PER YEAR. THE QUEUE NODE AND
* RESOURCE DATA CAN BE USED TO DETERMINE WHAT PORTION(S) OF
* THE SYSTEM IS/ARE LIMITING THE LAUNCH RATE.
*****

```

FUNCTION UF (IFN)

 * THIS IS A FUNCTION PROVIDED FOR BY Q-GERT THAT ALLOWS THE *
 * USEP TO MAKE MODIFICATIONS TO TRANSACTIONS AND ACTIVITIES. *
 * FUNCTION UF IS CALLED AT NODES SPECIFIED BY THE PROGRAMER *
 * WITH THE ARGUMENT IFN. THE VALUE OF IFN DETERMINES WHICH OF *
 * THE VARIOUS IF-THEN BLOCKS IS TO BE EXECUTED. VALUES *
 * ARE RETURNED IN UF. THE OVAR COMMON BLOCK IS REQUIRED BY *
 * Q-GERT. FOR A DETAILED DESCRIPTION OF THE VARIABLES IN THIS *
 * COMMON SEE "MODELING AND ANALYSIS USING Q-GERT NETWORKS," *
 * BY A. ALAN B. PRITSKER, PAGES 243-248. THE UCOM COMMON *
 * BLOCK VARIABLES ARE: *
 * *
 * 1. TTANK-THE TIME AFTER WHICH THE NEXT EXTERNAL TANK *
 * MUST BE SENT TO VAFB, *
 * 2. TLAND-THE TIME AFTER WHICH THE NEXT ORBITER MUST *
 * LAND AT VAFB, AND *
 * 3. TEND2-THE GREATEST END TIME FOR SRB STACKING. *
 * *
 * THESE VARIABLES WILL BE FURTHER DESCRIBED WHEN THEY ARE USED. *

COMMON /OVAR/ NDE,NETBU(100),NRFL(100),NRFLP(100),
 1 NRFL2(100),NRUN,NRUNS,NTC(100),PARAM(100,4),TBEG,TNOW
 COMMON /UCOM/ TTANK,TLAND,TEND2

 * CP IS THE CULMILATIVE PROBABILITY OF THE VARIOUS TYPES OF *
 * PAYLOADS ASSOCIATED WITH THE NUMBERS IN VAL. THE DIFFERENT *
 * TYPES OF PAYLOADS AND THEIR INDIVIDUAL AND CULMULATIVE *
 * PROBABILITIES ARE: *
 * *
 * PAYLOAD NO TYPE PROB CUL PROB *
 * 1 SPACELAR .172 .172 *
 * 2 HORIZONTAL .345 .517 *
 * 3 VERTICLE .483 1.000 *
 * *
 * A HORIZONTAL PAYLOAD IS ONE THAT IS LOADED IN THE OPF. *
 * A VERTICLE PAYLOAD IS ONE THAT IS LOADED AT THE LAUNCH PAD. *
 * THESE TWO VARIABLES (CP AND VAL) ARE USED TO DETERMINE *
 * THE NEXT PAYLOAD THAT THE ORBITER WILL CAPRY. *

REAL CP(3), VAL(3)
 DATA CP/.172,.517,1.0/, VAL/1.0,2.0,3.0/

```

*****
* THIS BLOCK IS CALLED AT NODE ONE AND IT RETURNS TO ATTRI- *
* BUTE ONE THE NUMBER OF MISSIONS THAT EACH ORBITER HAS AT THE *
* START OF THE SIMULATION RUN. GATRB(2) GETS THE VALUE OF *
* ATTRIBUTE TWO WHICH IS THE ORBITER NUMBER AND USES THIS *
* VALUE TO DETERMINE THE NUMBER OF PREVIOUS MISSIONS FOR THE *
* ORBITER. AS AN EXAMPLE, IF ATTRIBUTE TWO EQUALS ONE (THE *
* FIRST ORBITER) THEN ATTRIBUTE ONE (NUMBER OF MISSIONS) IS *
* SET TO 21. THIS IS DONE AT THE BEGINNING OF THE EACH RUN. *
*****

```

```

      IF (IFN.EQ.1) THEN
        IF (GATRB(2).EQ.1.0) THEN
          UF = 21.0
        ELSE IF (GATRB(2).EQ.2.0) THEN
          UF = 18.0
        ELSE
          UF = 9.0
        END IF
      END IF

```

```

*****
* THIS BLOCK IS CALLED AT NODE 45 AND IS USED TO MOVE THE *
* VALUE OF THE LAST ORBITER PAYLOAD (UP PAYLOAD) IN ATTRI- *
* BUTE 4 TO ATTRIBUTE 3 WHICH IS THE DOWN PAYLOAD. *
*****

```

```

      IF (IFN.EQ.3) THEN
        UF = GATRB(4)
      END IF

```

```

*****
* THIS BLOCK IS CALLED FROM NODE 4 AND IS USED TO DETERMINE *
* THE NEXT PAYLOAD (UP PAYLOAD) FOR THE ORBITER. THE PAY- *
* LOAD IS SELECTED USING THE DPROB FUNCTION AND THE VARIABLES *
* CP AND VAL. THE ARGUMENTS FOR THE FUNCTION ARE CP (THE *
* CULMULATIVE PROBABILITY FOR EACH CHOICE), VAL (THE VALUE *
* OF EACH POSSIBLE CHOICE), THE NUMBER OF POSSIBLE CHOICES, *
* AND THE NUMBER OF THE RANDOM NUMBER STRING TO BE USED. *
* THE RANDOM NUMBER STRING IS INTRINSIC TO O-GERT. DPROB *
* USES A MONTE CARLO SELECTION TECHNIQUE TO SELECT THE PROB- *
* ABILITY AND THUS THE VALUE OF THE CHOICE. DPROB RETURNS *
* ONE OF THE 3 POSSIBLE VALUES IN VALUE TO UF. THIS VALUE *
* IS THEN PLACED IN ATTRIBUTE 4 (UP PAYLOAD). *
*****

```

```

      IF (IFN.FO.4) THEN
        UF = DPROB(CP,VAL,3,2)
      END IF

```

```

*****
* THIS BLOCK IS CALLED FROM NODE 13 AND DETERMINES THE TYPE *
* OF SSME PERIODIC SIGNIFICANT SPECIAL TASK THAT MUST BE *
* PERFORMED (IF ANY). THE TYPE OF PSST THAT IS DONE DE- *
* PENDS ON THE NUMBER OF MISSIONS THAT THE ORBITER HAS BEEN *
* ON. THE NUMBER OF MISSIONS OF THE ORBITER IS MAINTAINED *
* IS ATTRIBUTE 3 AND IS RETRIEVED USING THE GATRB FUNCTION. *
* THIS NUMBER IS THEN COMPARED AGAINST THE PSST REQUIREMENTS *
* TO DETERMINE WHICH TASKS ARE REQUIRED. IF TWO PSSTS ARE *
* REQUIRED THE ONE WITH THE LONGEST REQUIRED TIME IS DONE. *
* THE PSSTS AND THE FLIGHTS ON WHICH THEY ARE REQUIRED ARE: *
*
* 1. HIGH PRESSURE FUEL TURBO PUMP INSPECT: EVERY 2 FLIGHTS *
* 2. HIGH PRESSURE OXIDIZER TURBO PUMP: EVERY 5 FLIGHTS *
* 3. ENGINE REMOVAL AND REINSTALLATION: EVERY 9 FLIGHTS *
*
* AS AN EXAMPLE IF THE NUMBER OF MISSIONS IS A MULTIPLE OF *
* 2 THEN UF IS SET EQUAL TO 1 AND THIS IN TURN SETS ATTRIBUTE *
* 5 TO 1. THE TRANSACTION THEN BRANCHES ON A/TRIBUTE 5 AND *
* SCHEDULES THE TASK REQUIRED EACH TWO FLIGHTS. *
*****

```

```

IF (IFN.EQ.5) THEN
  AT1 = GATRB(1)
  IF (AT1.EQ.0.0) THEN
    UF = 4.0
  ELSE IF (AMOD(AT1,2.0).EQ.0.0) THEN
    UF = 1.0
  ELSE IF (AMOD(AT1,5.0).EQ.0.0) THEN
    UF = 2.0
  ELSE IF (AMOD(AT1,9.0).EQ.0.0) THEN
    UF = 3.0
  ELSE
    UF = 4.0
  END IF
END IF

```

```

*****
* THIS BLOCK IS CALLED FROM NODE 19 AND DETERMINES THE TYPE *
* OF ORBITER PSST THAT MUST BE PERFORMED (IF ANY). THE *
* METHOD OF SELECTION IS THE SAME AS IN THE ABOVE BLOCK. *
* THE PSSTS AND THE FLIGHTS ON WHICH THEY ARE REQUIRED ARE: *
*
* 1. PAYLOAD BAY THERMAL CTL SYS REPLACEMENT: EVERY 40 FLTS *
* 2. PARTIAL PLB THERMAL CTL SYS REPLACEMENT: EVERY 33 FLTS *
* 3. FUEL CFLR REMOVAL AND REPLACEMENT: EVERY 12 FLTS *
* 4. APU REPLACEMENT: EVERY 13 FLTS *
*****

```

```

IF (IFN.EQ.6) THEN
  ATI = GATRB(1)
  IF (ATI.EQ.0.0) THEN
    UF = 5.0
  ELSE IF (AMOD(ATI,40.0).EQ.0.0) THEN
    UF = 1.0
  ELSE IF (AMOD(ATI,33.0).EQ.0.0) THEN
    UF = 2.0
  ELSE IF (AMOD(ATI,12.0).EQ.0.0) THEN
    UF = 3.0
  ELSE IF (AMOD(ATI,13.0).EQ.0.0) THEN
    UF = 4.0
  ELSE
    UF = 5.0
  END IF
END IF

```

```

*
*****
* THIS BLOCK IS CALLED AT NODE 44 AND IS USED TO SELECT THE *
* LANDING SITE FOR THE ORBITER. THE CURRENT SIMULATION TIME *
* IS COMPARED TO THE TIME CONTAINED IN TLAND (THE TIME AFTER *
* WHICH THE NEXT ORBITER MUST BE SENT TO VAEB). IF TNOW IS *
* GREATER THEN TLAND THEN A TWO IS PLACED INTO ATTRIBUTE SEVEN *
* AND THE ORBITER IS SENT TO VAEB. TLAND IS THEN UPDATED TO *
* REFLECT THE TIME AT WHICH THE NEXT ORBITER IS SENT TO VAEB. *
* IF TNOW IS NOT GREATER THEN TLAND THEN A ONE IS PLACED INTO *
* ATTRIBUTE SEVEN AND THE ORBITER IS SENT TO KSC. THE VALUE *
* ADDED TO TLAND (36.5) IS SELECTED SO AS TO SENT TEN ORBITERS *
* TO VAEB A YEAR. THE ORBITERS ARE SENT TO THE CHOSEN LAND- *
* ING SITE BY BRANCHING FROM NODE 44 ON THE VALUE IN ATTRIBUTE *
* SEVEN. *
*****
*

```

```

IF (IFN.EQ.7) THEN
  IF (TNOW.GT.TLAND) THEN
    UF = 2.0
    TLAND = TLAND + 36.5
  ELSE
    UF = 1.0
  END IF
END IF

```



```

*****
* THIS BLOCK IS CALLED FROM NODE 80 AND IS USED TO SELECT THE *
* DESTINATION FOR THE EXTERNAL TANK AFTER PRODUCTION. THE *
* BLOCK USES THE SAME LOGIC AS THAT DESCRIBED FOR THE SELFC- *
* TION OF THE LANDING SITE FOR THE ORBITER MENTIONED ABOVE. *
* THIS BLOCK ALSO SENDS TEN EXTERNAL TANKS A YEAR TO VAB. *
*****

```

```

IF (TEN.FO.8) THEN
  IF (TNOW.GT.TTANK) THEN
    UF = 2.0
    TTANK = TTANK + 36.5
  ELSE
    UF = 1.0
  END IF
END IF

```

```

*****
* THIS BLOCK IS CALLED PRIOR TO SRB STACKING IN THE VAB. THIS *
* IS DONE TO DELAY OTHER ACTIVITIES IN THE VAB DUE TO SAFETY *
* REQUIREMENTS. THE LENGTH OF THE SRB STACKING PROCFESS (TIME) *
* IS DETERMINED FIRST USING PARAMETER SET 26. THE END TIME *
* FOR THE STACKING IS DETERMINED BY ADDING THE STACK TIME TO *
* THE CURRENT SIMULATION TIME (TNOW). THE END TIME FOR THIS *
* STACK (TEND1) IS COMPARED TO THE LAST SRB STACK END TIME *
* (TEND2). IF TEND1 IS LESS THEN TEND2 THEN THE OTHER ACTIV- *
* ITIES ARE ALREADY DELAYED PASSED THE STACK TIME AND THERE *
* IS NO NEED TO EXTEND THEM ANY MORE. IF TEND1 IS GREATER *
* THAN TEND2 THEN THE VAB ACTIVITIES MUST BE DELAYED. IF *
* THERE ARE NO CURRENT SRB STACKINGS OCCURRING THEN THE ACT- *
* ARE DELAYED FOR THE FULL TIME OF THE CURRENT STACK (TIME). *
* IF THERE IS ANOTHER SRB STACK IN PROCESS THEN THE ACTIVITIES *
* ARE EXTENDED BY THE DIFFERNC E BETWEEN THE CURRENT STACK *
* TIME AND THE NEW STACK TIME. THE ACTIVITIES ARE DELAYED BY *
* USING THE XTEND SUBROUTINE. THIS SUBROUTINE IS INTRINSIC *
* TO Q-GERT AND HAS TWO ARGUMENTS. THE FIRST ARGUMENT IS THE *
* ACTIVITY NUMBER OF THE ACTIVITY TO BE DELAYED AND THE SECOND *
* ARGUMENT IS THE LENGTH OF TIME THAT THE ACTIVITY IS TO BE *
* DELAYED. IF THE ACTIVITY TO BE DELAYED IS NOT CURRENTLY IN *
* PROGRESS THEN THE REQUEST IS IGNORED. FINALLY, THE PROCESS *
* TIME FOR THE SRB STACK IS PLACED IS ATTRIBUTE SIX AND THE *
* ACTIVITY IS BEGUN.
*****

```

```

IF (IFN.FO.9) THEN
  TIME = BF(26)
  TEND1 = TIME + TNOW
  IF (TEND1.GT.TEND2) THEN
    IF (TNOW.GT.TEND2) THEN
      TIME1 = TIME
    ELSE
      TIME1 = TEND1 - TEND2
    END IF
    CALL XTEND (32,TIME1)
    CALL XTEND (62,TIME1)
    CALL YTEND (65,TIME1)
    CALL XTEND (69,TIME1)
    CALL XTEND (70,TIME1)
    CALL XTEND (77,TIME1)
    TEND2 = TEND1
  END IF
  UF = TIME
END IF

```

```

*
*****
* THIS BLOCK IS CALLED PRIOR TO MATING THE ORBITER TO THE SRB/ *
* ET ASSEMBLY. FIRST THE PROCESS TIME FOR THE MATING IS DE- *
* TERMINED (TIME2) USING PARAMETER SPT 20. IF THERE IS A SRB *
* STACK CURRENTLY IN PROGRESS THEN THE PROCESS TIME IS EXTENDED*
* BY THE AMOUNT OF TIME LEFT TO COMPLETE THE SRB STACK. THIS *
* IS DONE FOR SAFETY REASONS THAT DO NOT ALLOW ANY OTHER VAB *
* ACTIVITIES WHEN THERE IS AN SRB STACK OCCURING IN THE VAB. *
* IF THERE IS NOT A SRB STACK IN PROGRESS THEN THE ORIGINAL *
* TIME FOR THE ORBITER MATE IS USED AS THE ACTIVITY TIME. *
*****
*

```

```

IF (IFN.FO.10) THEN
  TIME2 = BF(20)
  IF (TEND2.GT.TNOW) THEN
    TIME2 = TIME2 + (TEND2 - TNOW)
  END IF
  UF = TIME2
END IF

```

```

*
*****
* THIS BLOCK IS CALLED PRIOR TO MLP REFURBISHMENT IN THE VAB. *
* THE PROCESS TIME IS THEN EXTENDED IN THE MANNER DESCRIBED *
* PREVIOUSLY IF A SRB STACK IS IN PROGRESS. A CONSTANT TIME *
* IS USED FOR THE ORIGINAL MLP REFURBISHMENT TIME. *
*****
*

```

```

IF (IFN.FO.11) THEN
  IF (TEND2.GT.TNOW) THEN
    UF = 3.43 + (TEND2 - TNOW)
  ELSE
    UF = 3.43
  END IF
END IF

```

```

*****
* THIS BLOCK DETERMINE THE PROCESS TIME FOR THE SRB CHECKOUT *
* OPERATIONS USING PARAMETER SET 27. IF THERE IS A SRB STACK *
* CURRENTLY IN PROGRESS THEN THE ACTIVITY TIME IS EXTENDED AS *
* PREVIOUSLY DESCRIBED. *
*****

```

```

*
  IF (IFN.EQ.12) THEN
    TIME3 = BE(27)
    IF (TEND2.GT.TNOW) THEN
      TIME3 = TIME3 + (TEND2 - TNOW)
    END IF
    UF = TIME3
  END IF

```

```

*****
* THIS BLOCK CALCULATES THE ET MATE PROCSS TIME USING PARA *
* METER SET 28. THE TIME IS EXTENDED AS ABOVE WHEN REQUIRED. *
*****

```

```

*
  IF (IFN.EQ.13) THEN
    TIME4 = BE(28)
    IF (TEND2.GT.TNOW) THEN
      TIME4 = TIME4 + (TEND2 - TNOW)
    END IF
    UF = TIME4
  END IF

```

```

*****
* THIS BLOCK CALCULATES THE ET/SRB CHECKOUT OPERATIONS TIME *
* USING PARAMETER SET 29. THE TIME IS EXTENDED AS REQUIRED IN *
* THE SAME MANNER AS ABOVE. *
*****

```

```

*
  IF (IFN.EQ.14) THEN
    TIME5 = BE(29)
    IF (TEND2.GT.TNOW) THEN
      TIME5 = TIME5 + (TEND2 - TNOW)
    END IF
    UF = TIME5
  END IF

```

```

*****
* THIS BLOCK CALCULATES THE FT CHECKOUT OPERATIONS TIME USING *
* PARAMETER SET 30. THE TIME IS EXTENDED AS ABOVE WHEN NEEDED *
*****

```

```

      IF (IEF.EQ.15) THEN
        TIME6 = RF(30)
        IF (TEND2.GT.TNOW) THEN
          TIME6 = TIME6 + (TEND2 - TNOW)
        END IF
        BE = TIME6
      END IF
      RETURN
    END

```

```

*****
* THIS SUBROUTINE IS CALLED AUTOMATICALLY BY THE O-GERT ANAL *
* YSIS PROGRAM AT THE BEGINNING OF EACH RUN OF THE NETWORK. *
* THIS SUBROUTINE IS USED TO INITIALIZE THE VALUES OF TTANK, *
* TLAND, AND TEND2. IN ADDITION, ON THE FIRST RUN, THE PARA *
* METER SETS USED IN THE USER FUNCTION ABOVE (20, 26, 27, 28, *
* 29, AND 30) ARE INITIALIZED. CPRP IS AN INTRINSIC ROUTINE *
* IN O-GERT THAT IS USED TO INITIALIZE PARAMETER SETS TO BE *
* UTILIZED AS A BETA-PERT DISTRIBUTION. *
*****

```

```

SUBROUTINE UI
COMMON /QVAR/ NDE,NFTBU(100),NREL(100),NRFLP(100),
1 NREL2(100),NRUN,NRUNS,NTC(100),PARAM(100,4),TBEG,TNOW
COMMON /UCOM/ TTANK, TLAND, TEND2
TTANK = 36.50
TLAND = 36.50
TEND2 = 0.0
IF (NRUN.EQ.1) THEN
  CALL CPRP(20)
  CALL CPRP(26)
  CALL CPRP(27)
  CALL CPRP(28)
  CALL CPRP(29)
  CALL CPRP(30)
END IF
RETURN
END

```

 * THE FOLLOWING PORTION OF THE PROGRAM IS THE O-GERT COMPUTER *
 * REPRESENTATION OF THE NETWORK DESIGNED TO DEPICT THE STS *
 * FLOW AT MSC. THE PROGRAM UTILIZED THE O-GERT ANALYSIS PRO- *
 * GRAM TO ANALYSE THE SYSTEM. FOR A FULL DESCRIPTION OF THE *
 * PROGRAM STATEMENTS AND THEIR PARAMETERS SEE "MODELING AND *
 * ANALYSIS USING O-GERT NETWORKS", BY A. ALAN B. PRITSKER. *
 * THE PROGRAM ACCOMPLISHES 10 RUNS OF THE MODEL WITH *
 * EACH RUN BEING 4015 DAYS IN LENGTH. THE FIRST 365 DAYS ARE *
 * IGNORED FOR STATISTICAL CALCULATIONS. THE OUTPUT IS A SUM- *
 * MARY OF ALL TEN OF THE RUNS. *

*
 *
 *

GFN,ANDRUSYSZYN,KSCOPS,10,30,1982,12,,,4015,10,S,365,8*	
SOU,1,0,1,A*	SOURCE FOR ORBITERS
VAS,1,2,IN,1,1,UF,1,3,CO,2,8,CO,10*	
ACT,1,1,CO,0,0,1,(9)A2.LE.2*	GENERATES ORBITERS
ACT,1,2,CO,0,0,2,(9)A2.LE.3*	SENDS ORBITERS TO WAIT FOR
*	OFF
OPF,2/WAITOPF,(10)3*	ORBITERS WAIT FOR OFF BAY
RES,1/OPFBAY,,,3*	ESTABLISHES THE NUMBER OF
*	OFF BAYS (2). TO ADD OR
*	DELETE BAYS PUT THE DE-
*	SIREN NUMBER IN PLACE
*	OF THE 2
ALL,3,,1,1,2/4*	ALLOTS OFF BAY
REG,4,1,1,0,M*	ORBITER ENTERS THE OFF AND
*	IS MARKED WITH THE CURRENT
*	TIME
VAS,4,4,UF,4*	SELECTS UP PAYLOAD
ACT,4,5,BP,1,3/SAFEORB*	ORBITER IS SAFED PRIOR TO
*	SERVICING
REG,5,1,1*	
ACT,5,6,BP,2,4/PLBACCES*	PLB ACCESS IS GAINED
REG,6,1,1,F*	
ACT,6,7,BP,3,5/REHORPL,(9)A4.LE.2*	REMOVE HORIZONTAL PAYLOAD
ACT,6,7,BP,4,6/REVERPL,(9)A4.EO.3*	REMOVE VERTICAL PAYLOAD
REG,7,1,1,F*	
ACT,7,8,BP,5,7/HORFLKT,(9)A4.LE.2*	INSTALL HOR. FLIGHT KIT
REG,8,1,1*	
ACT,8,9,BP,6,8/INHORPL*	INSTALL HOR. PAYLOAD
REG,9,1,1*	
ACT,9,10,BP,7,9/HORPLCKOUT*	HOR. PAYLOAD CHECKOUT
ACT,7,10,BP,8,10/VERPLTKT,(9)A4.EO.3*	INSTALL VER. FLIGHT KIT
REG,10,1,1*	
ACT,10,11,BP,9,11/FINALCO*	FINAL PLR CHECKOUT
OPF,11/WAITMAINT,(10)25*	WAITS FOR OFF MAINT. ACT-
*	IVITIES TO BE COMPLETED

ACT, 5, 12, BP, 10, 12/SSMEHMAINT*
QUE, 12/WAITPSST, (10)15*

ROUTINE SSME MAINT.
WAITS FOR SSME PSST
TO BE COMPLETED

*
ACT, 5, 13, CO, 0.0, 13*
REG, 13, 1, 1, F*
VAS, 13, 5, UF, 5*

SELECTS SSME PSST TO
BE COMPLETED

*
ACT, 13, 14, BP, 11, 14/SSPSST1, (9)A5.EQ.1*
ACT, 13, 14, BP, 12, 15/SSPSST2, (9)A5.EQ.2*
ACT, 13, 14, BP, 13, 16/SSPSST3, (9)A5.EQ.3*
ACT, 13, 14, CO, 0.0, 17/NOSSPSST, (9)A5.EQ.4*
QUE, 14/WAITSSME, (10)15*

WAITS COMPLETION OF
ROUTINE SSME MAINT.
WHEN ALL SSME MAINT. IS
COMPLETED THE TRANSACTIONS
ARE COMBINED INTO ONE
TRANSACTION

*
NAT, 15, 2, 12/16, 14/16*
*
*
*

REG, 16, 2, 2*
ACT, 16, 17, CO, 0.0, 18*
QUE, 17/SSMEWAIT, (10)25*

WAIT FOR OTHER OPF
ACTIVITIES

*
ACT, 5, 18, BP, 14, 19/SCHMAINT*
QUE, 18/WAITPSST, (10)21*
ACT, 5, 19, CO, 0.0, 20*
REG, 19, 1, 1, F*
VAS, 19, 5, UF, 6*

ROUTINE ORBITER MAINT.
WAIT FOR PSST MAINT.

ACT, 19, 20, BP, 15, 21/ORBPSST1, (9)A5.EQ.1*
ACT, 19, 20, BP, 16, 22/ORBPSST2, (9)A5.EQ.2*
ACT, 19, 20, BP, 17, 23/ORBPSST3, (9)A5.EQ.3*
ACT, 19, 20, BP, 18, 24/ORBPSST4, (9)A5.EQ.4*
ACT, 19, 20, CO, 0.0, 25/NOPSSST, (9)A5.EQ.5*
QUE, 20/WAITSCH, (10)21*
NAT, 21, 2, 18/22, 20/22*

SELECT ORBITER PSST

WAIT ROUTINE ORP MAINT
WHEN ALL ORBITER SCHEDULED
MAINT IS COMPLETE THE
TRANSACTIONS ARE COMBINED

*
REG, 22, 2, 2*
ACT, 22, 23, CO, 0.0, 26*
QUE, 23/SCHWAIT, (10)25*
ACT, 5, 24, BP, 19, 27/TPSMAINT*
QUE, 24/TPSWAIT, (10)25*

WAIT FOR OTHER OPF ACT.
TPS MAINTENANCE
WAIT FOR OTHER OPF ACT.
TO BE COMPLETED

*
NAT, 25, 2, 11/26, 17/26, 23/26, 24/26*
*
*
*

WHEN ALL OPF ACTIVITIES
ARE COMPLETE THE TRANS-
ACTIONS ARE COMBINED BACK
INTO ONE TRANSACTION
THE TIME ORBITER WAS
IN THE OPF IS RECORDED

STA, 26/OPFTIME, 4, 4, D, I*
*
ACT, 26, 27, CO, 0.0, 28*
QUE, 27/ORBWAIT, (10)28*

ORBITER WAITS TO BE MATED

SEL, 28/ORB MATF, ASN, , B/8, , 27, 78*

*
*
*

ACT, 28, 24, CO, 0.0, 29*

FRF, 29, , 1, 1, 3*

*

ACT, 29, 30, CO, 0.09, 30/TOWTOVAR*

REG, 30, 1, 1*

VAS, 30, 6, HF, 10*

ACT, 30, 32, AT, 6, 32/MATEORB*

OPF, 32/WAITCRAW, (10)33*

RES, 2/CRAWLER, 1, 33*

*
*
*

ALL, 33, , 2, 1, 32/34*

OPF, 34/WAITPAD, (10)35*

RES, 3/PAD, 2, 35*

*
*
*
*

ALL, 35, , 3, 1, 34/36*

REG, 36, 1, 1*

ACT, 36, 98, CO, 0.0, 84*

FRF, 98, , 6, 1, 66*

ACT, 98, 94, CO, 0.0, 85*

STA, 99/RETVAR, 1, 1, D, B*

ACT, 36, 37, CO, 0.61, 33/TOWTOPAD*

REG, 37, 1, 1*

ACT, 37, 38, CO, 0.61, 34/RETCRAWLER*

FRF, 38, 2, 1, 33*

*

ACT, 38, 39, CO, 0.0, 35*

STA, 39/RETCRAWL, 1, 1, D, B*

ACT, 37, 40, BP, 21, 36/PADOPS*

*

STA, 40/LAUNCH, 1, 1, D, B*

*

*

VAS, 40, 1+, CO, 1*

ACT, 40, 41, CO, 6.83, 37/REFRRPAD*

FRF, 41, , 3, 1, 35*

*

ACT, 41, 42, CO, 0.0, 38*

STA, 42/RETPAD, 1, 1, D, B*

ACT, 40, 43, CO, 0.0, 39*

REG, 43, 1, 1, F*

ACT, 43, 44, NO, 22, 40/SLMISS, (9)A4.E0.1* SPACELAB MISSION TIME

ACT, 43, 44, NO, 23, 41/NOMMISS, (9)A4.GE.2* NOMINAL MISSION TIME

WHEN BOTH AN ORBITER
AND A SRB/ET ASSEMBLY
ARE AVAILABLE, THE ORBITER
MATING ACTIVITY IS BEGUN

THE OPF BAY IS FREED
FOR THE NEXT ORBITER
TOW ORBITER TO VAR

DETERMINE ORB MATE TIME
MATE ORBITER TO ASSEMBLY
ASSEMBLY WAITS FOR CRAWLER
ESTABLISHES NUMBER OF
CRAWLERS (1). TO ADD CRAW-
LERS PUT THE DESIRED NUM-
BER IN PLACE OF THE 1
ALLOTS CRAWLER
ASSEMBLY WAITS FOR PAD
ESTABLISHES THE NUMBER OF
PADS (2). IF IT IS DESIRED
TO ADD OR SUBTRACT PADS
CHANGE THE 2 TO THE
DESIRED NUMBER
ALLOTS PAD

FREE VAR

MOVE ASSEMBLY TO PAD

RETURN THE CRAWLER
FREE CRAWLER FOR
FURTHER USE

PAD OPERATIONS TO INCLUDE
THE COUNTDOWN
LAUNCH THE ORBITER AND
RECORD THE TIME BETWEEN
CONSECUTIVE LAUNCHES
UPDATE MISSION COUNT
REFURBISH LAUNCH PAD
FREE LAUNCH PAD FOR
FURTHER USE

REG,44,1,1,F*	SELECT LANDING SITE
VAS,44,7,UF,7*	LAND AT KSC
ACT,44,45,CO,0.0,42/KSCLND,(9)A7.LE.1*	LANDING QUEUE AT KSC
QUE,45/LANDKSC,0,0,(7)46*	MOVE UP PAYLOAD TO
VAS,45,3,UF,3*	DOWN PAYLOAD ATTRIBUTE
*	IF THE STRIP AT KSC IS IN
REG,46,1,1*	USE THEN THE LANDING OF
*	THE ORBITER IS DELAYED
*	UNTIL THE STRIP IS CLEAR
ACT,46,45,CO,0.4,43/DELYKSC*	KSC LANDING DELAYED
ACT,45,2,CO,0.09,44/LANDOPS*	KSC LANDING OPERATIONS
ACT,44,47,CO,0.0,45/LNDVAN,(9)A7.EQ.2*	ORBITER TO VAFB
QUE,47/VAFBLAND,0,0,(7)48*	LANDING QUEUE AT VAFB
REG,48,1,1*	IF THE LANDING STRIP
*	AT VAFB IS IN USE THEN
*	THE LANDING IS DELAYED
ACT,48,47,CO,0.4,46/DELYVAFB*	DELAY VAFB LANDING
ACT,47,49,CO,0.09,47/VLANDOPS*	VAFB LANDING OPERATIONS
SOU,31,0,1*	GENERATE INITIAL VAFB ORB
VAS,31,1,CO,7,2,CO,4,3,CO,3,8,CO,10*	SETS THE INITIAL VALUES
*	OF MISSION NUMBER, ORBITER
*	NUMBER AND DOWN PAYLOAD
*	FOR THE VAFB ORBITER
ACT,31,49,CO,0.0*	ORBITER WAITS FOR USE
QUE,49/VAFBWAIT*	AT VAFB
*	VAFB LAUNCH OPERATIONS
ACT,49,50,NO,24,48/VAFBOPS*	LAUNCH ORBITER FROM VAFB
STA,50/VAFBTINE,1,1,D,R*	AND RECORD THE TIME
*	BETWEEN LAUNCHES
*	UPDATE NUMBER OF MISSIONS
VAS,50,14,CO,1*	ORBITAL MISSION FROM VAFB
ACT,50,44,NO,23,49/VAFBMISSION*	SOURCE OF INITIAL AFT
SOU,51,0,1,A*	SKIRTS
*	
VAS,51,8,IN,1*	
ACT,51,51,CO,0.0,50/GFNAFTSK,(9)A8.LE.9*	GENERATE 10 AFT SKIRTS
ACT,51,52,CO,0.0,51,(9)A8.LE.10*	AFTER LAUNCH IMMEDIATELY
ACT,40,52,CO,0.0,52/RETAFTSK*	RETURN THE AFT SKIRTS
*	AFT SKIRTS WAIT FOR PSF
QUE,52/WAITPSF,(10)53*	ESTABLISHES THE INITIAL
RES,4/PSF,1,53*	NUMBER OF PSFS AT 1
*	TO ADD OR SUBTRACT PSFS
*	PUT THE DESIRED NUMBER
*	IN PLACE OF THE 1. IN
*	ADDITION CHANGE THE NUM-
*	BER 1 IN ACTIVITY 55 TO
*	THE DESIRED NUMBER OF PSFS
ALL,53,,4,1,52/54*	ALLOTS PSF

REG, 54, 1, 1*
 ACT, 54, 55, CO, 0.7, 53/AFTKSTAND*
 QUE, 55/WAITSPM, (10)57*
 ACT, 56, CO, 0.0, 54/RETSRM*
 QUE, 56/WAITAFTSK, 10, (10)57*
 *
 SFL, 57/AFTBUILD, ASM, (7)55, 56*
 ACT, 57, 58, BP, 25, 55/BUILDUP, 1*
 *
 *
 *
 QUE, 58/WAITSTOR, (10)59*
 RES, 5/SRBSTORE, 2, 59*
 *
 *
 *
 *
 ALL, 59, 5, 1, 58/60*
 REG, 60, 1, 1*
 ACT, 60, 61, CO, 0.0, 56*
 FRE, 61, 4, 1, 53*
 ACT, 61, 62, CO, 0.0, 57*
 STA, 62/RETSPF, 1, 1, D, B*
 ACT, 60, 63, CO, 0.0, 58*
 QUE, 63/WAITMLP, (10)69*
 SOU, 64, 1, 1, A*
 VAS, 64, 8, IN, 1*
 ACT, 64, 64, CO, 0.0, 59, (9)AB.LE.2*
 ACT, 64, 65, CO, 0.0, 60, (9)AB.LE.3*
 ACT, 40, 65, CO, 5.43, 61/WASHMLP*
 *
 QUE, 65/WAITVAR, (10)66*
 RES, 6/VAR, 2, 66*
 *
 *
 *
 *
 ALL, 66, 6, 1, 65/67*
 REG, 67, 1, 1*
 VAS, 67, 6, UF, 11*
 *
 ACT, 67, 68, AT, 6, 62/MLPREFURB*
 QUE, 68/WAITSRB, (10)69*
 SEL, 69/STACKSRB, ASM, (7)63, 68*
 *
 *
 ACT, 69, 70, CO, 0.0, 63*
 REG, 70, 1, 1*
 VAS, 70, 6, UF, 9*
 ACT, 70, 71, AT, 6, 64/SRRSTACK*
 ACT, 70, 96, CO, 0.0, 82*
 PRF, 96, 5, 1, 59*
 ACT, 96, 97, CO, 0.0, 83*
 STA, 97/RETSRBST, 1, 1, D, B*

INSTALL AFT SKIRT IN STAND
 AFT SKIRTS WAIT FOR SRM
 RETURN SRM AFTER LAUNCH
 SRM WAIT FOR AFT SKIRT
 STARTS WITH 10 IN QUEUE

AFT BUILDUP OF SRB IN PSF
 NUMBER OF SERVERS (1 IN
 THIS CASE) MUST EQUAL THE
 NUMBER OF PSFS
 SRBS WAIT STORAGE
 ESTABLISHES NUMBER OF SRB
 STORAGE BAYS AT 2. TO ADD
 OR DELETE STORAGE PLACE
 THE DESIRED NUMBER OF
 STORAGE BAYS IN PLACE OF
 THE 2
 ALLOT SRB STORAGE

FREE PSF

SRB WAITS FOR MLP AND VAR
 SOURCE FOR MLPS

GENERATE 3 MLPS
 WASH MLP AFTER LAUNCH AND
 MOVE TO WAIT FOR VAR
 MLP WAITS FOR VAR
 ESTABLISHES THE NUMBER OF
 VARS AT 2. TO ADD OR
 DELETE THE VARS PUT THE DE-
 SIRED NUMBER IN PLACE OF
 THE 2
 ALLOT THE VAR

DETERMINE MLP REFURBISH-
 MENT TIME
 REFURBISH MLP
 WAIT FOR SRB SET
 WHEN BOTH THE SRBS AND
 THE MLP/VAR ARE AVAILBLE
 SRB STACKING IS STARTED

DETERMINE SRB STACK TIME
 STACK SRBS ON MLP

FREE SRB STORAGE

REG,71,1,1*
 VAS,71,6,UF,12*
 *
 ACT,71,72,AT,6,65/SRBALINE*
 QUE,72/WAITFT,(10)73*
 SEL,73/ETMATE,ASH,(7)72,94*
 *
 *
 ACT,73,74,CO,0.0,66*
 REG,74,1,1*
 VAS,74,6,UF,13,8,CO,0*
 ACT,74,77,AT,6,69/MATEET*
 ACT,74,75,CO,0.0,67*
 FRF,75,,0,1,90T
 ACT,75,76,CO,0.0,68*
 STA,76,RETETSTORE,1,1,D,B*
 REG,77,1,1*
 VAS,77,6,UF,14*
 *
 ACT,77,78,AT,6,70/ETSRBCO*
 QUE,78/WAITORB,(10)28*
 COU,79,0,1,D*
 ACT,79,79,CO,15.21,71/PRODETS*
 *
 *
 *
 *
 *
 ACT,79,80,CO,0.0,72*
 REG,80,1,1,F*
 VAS,80,7,UF,8*
 ACT,80,81,CO,0.0,73/ETTKSC,(9)A7.FO.1*
 QUE,81/WAITBARG,(10)82*
 RES,7/KSCBARGE,4,82*
 *
 *
 *
 *
 ALL,82,,7,1,81/83*
 REG,83,1,1*
 ACT,83,84,CO,7.0,74/SHIPTOKSC*
 QUE,84/WAITFTCO,(10)85*
 *
 RES,8/ETCOCFL,2,85*
 *
 *
 *
 *
 *
 ALL,85,,P,1,84/86*

DETERMINE SRB CHECKOUT
 TIME
 SRB CHECKOUT AND ALIGNMENT
 WAIT FOR EXTERNAL TANK
 WHEN AN ET AND STACKED
 SRB ARE AVAILABLE THEN THE
 ET MATING IS BEGUN

DETERMINES ET MATE TIME
 MATE ET TO SRB

FREE ET STORAGE

DETERMINE ET/SRB CHECKOUT
 TIME
 ET/SRB CHECKOUT
 WAIT FOR ORBITER MATE
 SOURCE FOR EXTERNAL TANKS
 PRODUCE ETS AT A RATE
 OF 24 PER YEAR. TO IN-
 CREASE THE PRODUCTION RATE
 CHANGE THE DAYS BETWEEN
 PRODUCTION (CURRENTLY
 15.21) TO THE DESIRED RATE

DETERMINE ET DESTINATION
 ET SENT TO KSC
 ET WAITS FOR BARGE
 ESTABLISHES THE NUMBER OF
 KSC BARGES (4). TO ADD OR
 DELETE BARGES PUT THE DE-
 SIRED NUMBER IN PLACE OF
 THE 4
 ALLOT KSC BARGE TO ET

SHIP ET TO KSC
 ET WAITS AT KSC FOR
 AN ET CHECKOUT CELL
 ESTABLISHES THE NUMBER OF
 ET CHECKOUT CELLS (2). TO
 ADD OR DELETE CHECKOUT
 CELLS PUT THE DESIRED
 NUMBER OF CELLS IN PLACE
 OF THE 2
 ALLOT ET CHECKOUT CELL

PFC,86,1,1*
VAS,86,6,UF,15*
ACT,86,87,CO,7.0,75/RETARGE*
FRE,87,,7,1,82*
ACT,87,88,CO,0.0,76*
STA,88/RETKEAR,1,1,D,B*
ACT,86,89,AT,6,77/ETCOOPS*
QUE,89/WAITTST,(10)90*
RES,9/ETSTORE,2,90*

*
*
*
*

ALL,90,,9,1,89/91*
REG,91,1,1*
ACT,91,92,CO,0.0,78*
FRE,92,,8,1,85*
ACT,92,93,CO,0.0,79*
STA,93/RETETCO,1,1,D,B*
ACT,91,94,CO,0.0,80*
QUE,94/WAITSRB,(10)73*

*

ACT,80,95,CO,0.0,81/ETTOVAN,(9)17.EQ.2*
STA,95/ETTOVAFB,1,1,D,B*
SFF,2,4675748392/I*

*

DETERMINE ET CHECKOUT TIME
RETURN BARGE TO MICHOUD
FREE BARGE TO SHIP NEW ET

ET CHECKOUT OPERATIONS
ET WAITS FOR STORAGE
ESTABLISHES THE NUMBER OF
ET STORAGE CELLS (2). TO
ADD OR DELETE CELLS PUT
THE DESIRED NUMBER IN
PLACE OF THE 2
ALLOT ET STORAGE

FREE ET CHECKOUT CELL

ET WAITS FOR SRB PRIOR
TO ET MATE
SEND ET TO VAFB

REINITIALIZES RANDOM
NUMBER SEED 2 EACH RUN

 * THE FOLLOWING LINES OF CODE ARE THE PARAMETER SETS USED IN *
 * THIS PROGRAM. THE FIRST NUMBER AFTER PAR IS THE PARAMETER *
 * SET NUMBER. THE NEXT NUMBER IS THE MOST LIKELY TIME *
 * IN THE BETA-PERT DISTRIBUTION EXCEPT FOR PARAMETER SETS 22, *
 * 23, AND 24, IN WHICH CASE THE NUMBER IS THE MEAN OF A NORMAL *
 * DISTRIBUTION. THE NEXT TWO NUMBERS ARE THE MINIMUM AND *
 * MAXIMUM TIMES FOR THE DISTRIBUTIONS. THE FOURTH NUMBER IN *
 * THE PARAMETER SETS USING THE NORMAL DISTRIBUTION IS THE *
 * STANDARD DEVIATION OF THE DISTRIBUTION. ALL OF THE VALUES *
 * ARE IN UNITS OF DAYS.

PAR,1,7.70,1.58,13.83*

SAFE AND DESERVICE
 ORBITER

PAR,2,2.80,0.48,5.12*

GAIN PLB ACCESS

PAR,3,2.10,0.26,3.94*

REMOVE HORIZONTAL PL

PAR,4,1.40,0.26,2.54*

REMOVE VERTICLE PL

PAR,5,5.60,2.10,9.10*

INSTALL HORIZONTAL

*

FLIGHT KIT

PAR,6,0.70,0.53,0.83*

INSTALL HORIZONTAL PL

PAR,7,6.30,1.58,11.03*

CHECKOUT HORIZONTAL PL

PAR,8,9.10,2.10,16.10*

INSTALL VERTICLE

*

FLIGHT KIT

PAR,9,9.80,2.10,17.59*

FINAL PLB CHECKOUT

PAR,10,18.90,2.10,35.70*

ROUTINE SSME MAINT

PAR,11,10.85,2.10,19.60*

HPFTP INSPECTION

PAR,12,10.50,2.10,18.90*

HPOTP INSPECTION

PAR,13,8.05,2.10,14.00*

ENG REMOVE & INSPECT

PAR,14,22.40,2.10,42.70*

ROUTINE SCHEDULED

*

ORBITER MAINTENANCE

PAR,15,27.30,2.10,52.50*

PLB TCS REPLACE

PAR,16,7.79,2.10,13.48*

PARTIAL PIB TCS REPLACE

PAR,17,4.64,2.10,7.18*

FUEL CELL REPLACE

PAR,18,3.15,2.10,4.20*

APU REPLACE

PAR,19,14.93,2.33,27.53*

TPS MAINTENANCE

PAR,20,4.20,1.31,7.09*

ORBITER MATE ACTIVITIES

PAR,21,26.60,2.10,51.10*

PAD OPERATIONS

PAR,22,12.00,7.00,30.00,3.00*

SPACELAB MISSION

PAR,23,4.00,2.00,6.00,1.00*

NOMINAL MISSION

PAR,24,32.25,31.00,33.00,0.5*

VAFB ORBITER OPS

PAR,25,23.10,8.75,37.45*

SRB AFT BUILDUP

PAR,26,4.90,2.84,6.96*

SRB STACKING OPS

PAR,27,4.90,2.84,6.96*

SRB CHECKOUT AND

*

ALIGNMENT

PAR,28,2.10,0.38,3.33*

ET MATE OPERATIONS

PAR,29,22.40,1.66,43.14*

SRB/ET CHECKOUT

PAR,30,18.90,4.55,33.25*

ET CHECKOUT OPS

FIN*

Table XXVI. KSC Beta-PERT Parameters

Act. Num.	Activity Description	Most-Likely			Optimistic			Pessimistic					
		Hours	2/5	3/5	3/7	Hours	2/5	3/5	3/7	Hours	2/5	3/5	3/7
3	Safe Orbiter	88.0	7.70	5.13	3.67	18.0	1.58	1.05	0.75	158.0	13.83	9.22	6.58
4	Gain Payload Bay Access	32.0	2.80	1.87	1.33	5.5	0.48	0.32	0.23	58.5	5.12	3.41	2.44
5	Remove Horizontal Payload	24.0	2.10	1.40	1.00	3.0	0.26	0.18	0.13	45.0	3.94	2.63	1.88
6	Remove Vertical Payload	16.0	1.40	0.93	0.67	3.0	0.26	0.18	0.13	29.0	2.54	1.69	1.21
7	Instal Horizontal Flt Kit	64.0	5.60	3.73	2.67	24.0	2.10	1.40	1.00	104.0	9.10	6.07	4.38
8	Instal Horizontal Payload	8.0	0.70	0.47	0.33	6.0	0.53	0.35	0.25	10.0	0.88	0.58	0.42
9	Horizontal Payload C/O	72.0	6.30	4.20	3.00	18.0	1.58	1.05	0.75	126.0	11.03	7.35	5.25
10	Instal Verticle Flt Kit	104.0	9.10	6.07	4.33	24.0	2.10	1.40	1.00	184.0	16.10	10.73	7.67
11	Final Orb/PL Checkout	112.0	9.80	6.53	4.67	24.0	2.10	1.40	1.00	201.0	17.59	11.73	8.38
12	Routine SSME Maintenance	216.0	18.90	12.60	9.00	24.0	2.10	1.40	1.00	408.0	35.70	23.80	17.00
14	SSME PSST #1	124.0	10.85	7.23	5.17	24.0	2.10	1.40	1.00	224.0	19.60	13.07	9.33
15	SSME PSST #2	120.0	10.50	7.00	5.00	24.0	2.10	1.40	1.00	160.0	18.90	12.60	9.00
16	SSME PSST #3	92.0	8.05	5.37	3.83	24.0	2.10	1.40	1.00	160.0	14.00	9.33	6.67
19	Orbiter Scheduled Maint.	256.0	22.40	14.93	10.67	24.0	2.10	1.40	1.00	488.0	42.70	28.47	20.33
21	Orbiter PSST #1	312.0	27.30	18.20	13.00	24.0	2.10	1.40	1.00	600.0	52.50	35.00	25.00
22	Orbiter PSST #2	89.0	7.79	5.19	3.71	24.0	2.10	1.40	1.00	154.0	13.48	8.99	6.42
23	Orbiter PSST #3	53.0	4.64	3.09	2.21	24.0	2.10	1.40	1.00	82.0	7.18	4.79	3.42
24	Orbiter PSST #4	36.0	3.15	2.10	1.50	24.0	2.10	1.40	1.00	48.0	4.20	2.80	2.00
27	TFS Maintenance	170.5	14.93	9.95	7.10	26.5	2.33	1.55	1.10	314.5	27.53	18.35	13.10
32	Orbiter Mate Activities	48.0	4.20	2.80	2.00	15.0	1.31	0.87	0.62	81.0	7.09	4.73	3.38
36	Pad Operations	304.0	26.60	17.73	12.67	24.0	2.10	1.40	1.00	584.0	51.10	34.07	24.33
55	Aft Buildup of SRB	264.0	23.10	15.40	11.00	100.0	8.75	5.83	4.17	428.0	37.45	24.97	17.83
64	SRB Stack	56.0	4.90	3.27	2.33	32.5	2.84	1.89	1.35	79.5	6.69	4.64	3.31
65	SRB Alignment and Verif.	56.0	4.90	3.27	2.33	32.5	2.84	1.89	1.35	79.5	6.69	4.64	3.31
69	Mate ET	24.0	2.10	1.40	1.00	10.0	0.88	0.59	0.42	38.0	3.33	2.22	1.59
70	ET/SRB Checkout Operations	256.0	22.40	14.93	10.67	19.0	1.66	1.11	0.79	493.0	43.14	28.76	20.54
77	ET Checkout Operations	216.0	18.90	12.60	9.00	52.0	4.55	3.03	2.17	380.0	33.25	22.17	15.83

Table XXVII. KSC Normal Parameters

Act. Num.	Activity Description	Mean	Minimum	Maximum	Standard Deviation
40	Spacelab Mission	12.00	7.00	30.00	3.00
41	Nominal Mission	4.00	2.00	7.00	1.00
48	VAFB Operations	32.35	31.00	33.00	0.20

Table XXVIII. KSC Constant Parameters

Act. Num.	Activity Description	Work Hours	2/5	3/5	3/7
30	Tow Orbiter to VAB	1.0	0.09	0.06	0.04
33	Tow to Pad	7.0	0.61	0.41	0.29
34	Return Crawler	7.0	0.61	0.41	0.29
37	Refurbish Pad	78.0	6.83	4.55	3.25
43	Delay KSC Landing	9.6	0.40	-	-
44	Landing Ops KSC	1.0	0.09	0.06	0.04
46	Delay VAFB Land	9.6	0.40	-	-
47	VAFB Landing Ops	1.0	0.09	0.06	0.04
53	Install Aft Skirt	8.0	0.70	0.47	0.33
61	Wash MLP	62.0	5.43	3.62	2.59
62	Refurbish MLP	39.0	3.41	2.28	1.63
74	Ship ET	-	7.00	-	-
75	Return Barge	-	7.00	-	-
			24/yr	40/yr	60/yr
71	Produce ETS		15.21	9.125	6.083

Table XXIX. KSC Model Results

Launch Rate	Orbiters	OFF	Pad	MLP	VAB	FSF	ET C/O Cell	ET Prod.
12.951	4	2 (2/5)	2 (2/5)	3	2 (2/5)	1 (2/5)	2 (2/5)	24
12.906	"	"	"	"	3 (2/5)	"	1 (2/5)	"
13.746	"	"	"	4	2 (2/5)	"	2 (2/5)	"
14.070	"	"	"	"	3 (2/5)	"	1 (2/5)	"
14.129	"	"	"	3	2 (3/5)	"	2 (2/5)	"
14.166	"	"	"	4	"	"	"	"
14.185	"	2 (3/5)	"	3	"	"	"	"
14.738	"	2 (2/5)	"	4	"	"	"	40
15.235	"	2 (3/5)	2 (3/5)	3	"	"	"	"
15.351	"	"	2 (2/5)	"	"	"	"	"
15.401	5	"	2 (3/5)	4	"	"	"	"
15.538	4	"	2 (2/5)	4	"	"	"	"
15.581	"	"	2 (3/5)	"	"	"	"	"
15.956	"	"	2 (2/5)	3	"	1 (3/5)	"	"
18.534	"	"	2 (3/5)	"	"	"	"	"
19.939	"	"	"	4	"	1 (3/7)	"	"
21.139	"	"	"	"	2 (3/7)	1 (3/5)	"	"
21.380	"	"	2 (3/7)	"	2 (3/5)	"	"	"
21.695	"	2 (3/7)	2 (3/5)	"	"	"	"	"
22.046	"	"	2 (3/7)	"	"	1 (3/7)	"	"
22.569	"	"	2	"	"	1 (3/5)	"	"
22.646	"	"	2 (3/5)	"	2 (3/7)	"	"	"
22.656	"	"	2 (3/7)	"	"	"	"	"
24.044	"	"	2	"	"	1 (3/7)	"	"
26.760	"	"	"	"	"	"	2 (3/5)	"
26.910	"	"	"	"	"	"	2 (3/7)	"
27.471	"	"	"	"	3 (3/7)	"	1 (3/7)	"
30.055	5	"	"	"	2 (3/7)	"	2 (3/5)	"
30.060	5	"	"	"	3 (3/7)	"	1 (3/7)	"

Table XXIX. KSC Model Results (cont.)

Launch Rate	Orbiters	OFF	Pad	MLP	VAB	PSF	ET C/O Cell	ET Prod.
30.454	5	2 (3/7)	2 (3/7)	4	2 (3/7)	1 (3/7)	2 (3/7)	60
30.570	"	"	"	"	"	"	2 (3/5)	"
30.955	"	"	"	"	3 (3/7)	"	2 (3/7)	"
31.007	"	"	"	5	"	"	1 (3/7)	"
31.140	"	"	"	4	"	"	2 (3/5)	"
31.198	"	"	"	5	"	"	2 (3/7)	"
31.344	"	"	"	4	"	"	1 (3/7)	"
32.680	"	"	"	"	"	"	2 (3/7)	"
33.464	6	3 (3/7)	"	"	"	2 (3/7)	"	"
35.558	5	2 (3/7)	"	5	4 (3/7)	"	"	"
37.416	6	"	"	"	"	"	"	"
37.721	7	"	"	"	"	"	"	"
37.616	6	"	"	"	3 (3/7)	"	"	"
38.951	"	"	"	"	4 (3/7)	"	"	"
39.208	7	"	"	"	"	"	"	"
39.930	6	3 (3/7)	"	6	"	"	"	"
40.201	6	"	"	5	"	"	"	"
40.928	7	"	"	"	"	"	"	"
41.197	"	2 (3/7)	"	"	"	"	"	"
41.637	6	3 (3/7)	"	"	"	"	"	"
43.681	7	3 (3/7)	"	"	"	"	"	"
43.681	"	"	"	7	"	"	"	"
48.462	"	"	3 (3/7)	6	"	"	"	"

See notes after Table XXV

Appendix B

VAFB Q-GERT Model

This appendix contains the VAFB Q-GERT simulation model. The graphical model is presented in Figure 7, followed by the computer listing of the Q-GERT program used and the parameters used in the model (Table XXX).

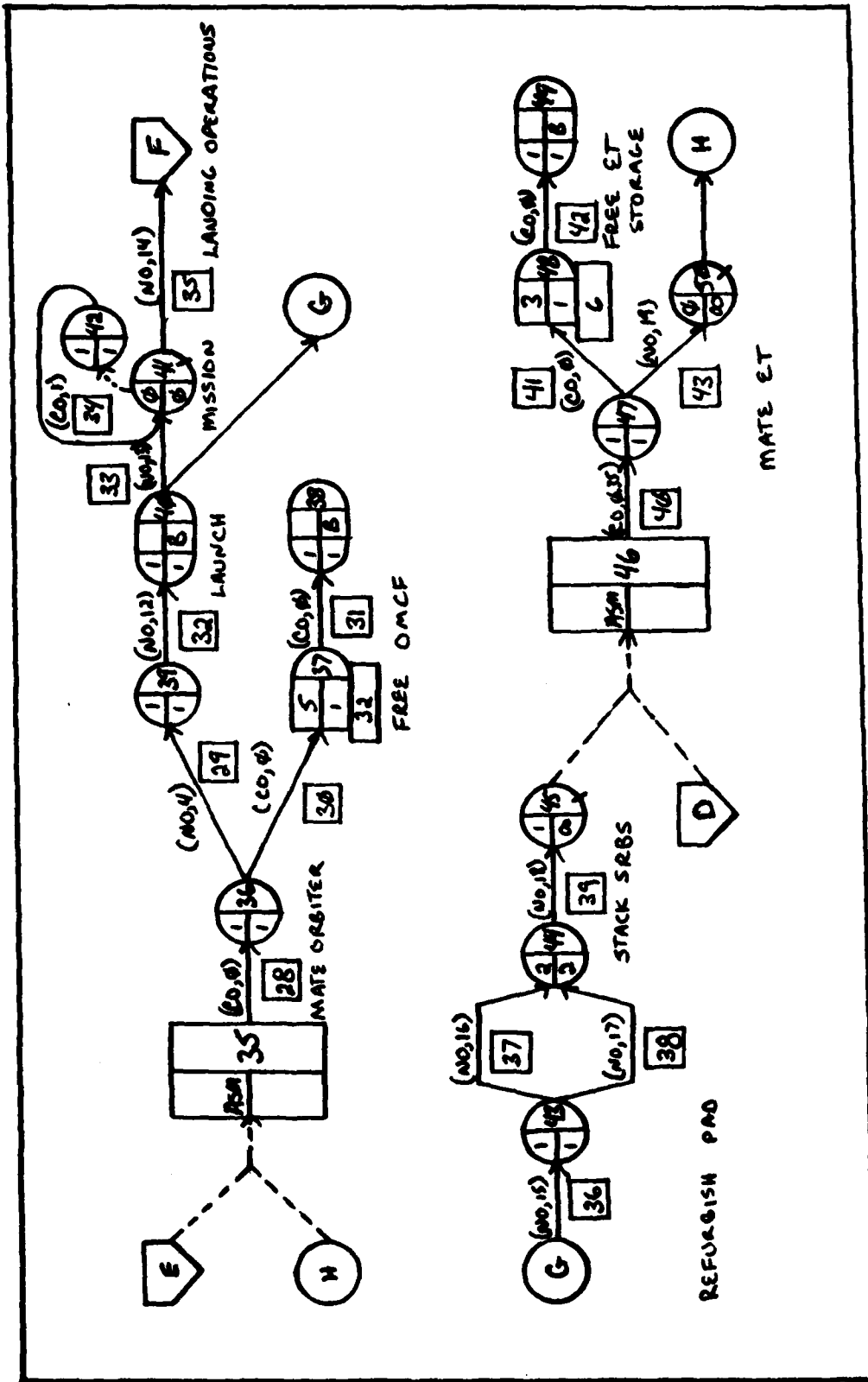


Figure 7. VAFF Q-CERT Graphical Model (Page 3 of 3)

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*****
* THIS PROGRAM IS THE Q-GERT CODE FOR A SIMPLATION MODEL *
* THAT DEPICTS THE FLOW OF THE SPACE TRANSPORTATION SYS- *
* TEM AT VANDENBERG AFB. HIS MODEL IS USED TO PREDICT THE *
* LAUNCH RATE CAPABILITY OF THE STS AT VAFB. THE MODEL *
* WAS DESIGNED TO DETERMINE LAUNCH RATE FOR ONLY THE CON- *
* FIGURATION USED IN THE MODEL, HOWEVER, THE USER CAN ALTER *
* THE MODEL TO EXAMINE OTHER CONFIGURATIONS OF THE SYSTEM. *
* THE PORTIONS THAT CAN BE EASILY VARIED ARE THE NUMBER OF *
* ORBITERS, THE NUMBER OF ORBITER CHECKOUT AND MAINTENANCE *
* FACILITIES (OMCF), THE NUMBER OF ET CHECKOUT AND STORF- *
* ACE CELLS, AND THE NUMBER AND TYPE OF ET BARGES USED TO *
* SHIP ETS TO VAFB. THIS MODEL ASSUMES THAT THERE ARE AN *
* UNLIMITED NUMBER OF ETS AND SRBS AVAILABLE TO THE SYSTEM. *
* IN ADDITION IT ASSUMES THAT THERE IS ONLY ONE LAUNCH PAD. *
* AS AN OUTPUT THE MODEL GIVES DATA ON THE TIME BETWEEN *
* LAUNCHES AND THE STATISTICS ON THIS DATA. IN ADDITION, *
* THE OUTPUT GIVES STATISTICS ON THE NUMBER AND AMOUNT OF *
* TIME THAT TRANSACTIONS WAIT IN THE VARIOUS QUEUES. *
*****

```

FUNCTION UF (IFN)

```

*****
* THIS IS A FUNCTION PROVIDED BY Q-GERT THAT ALLOWS THE *
* USER TO MAKE MODIFICATIONS TO TRANSACTIONS AND ACTIVITIES. *
* FUNCTION UF IS CALLED AT NODE SPECIFIED BY THE PROGRAMMER *
* WITH THE ARGUMENT IFN. VALUES CALCULATED IN THE FUNC- *
* TION ARE RETURNED IN UF. THE QVAR COMMON BLOCK CONTAINS *
* VARIABLES REQUIRED AND USED BY THE Q-GERT ANALYSIS PRO- *
* GRAM. FOR A DETAILED DESCRIPTION OF THE VARIABLES SEE *
* "MODELING AND ANALYSIS USING Q-GERT NETWORKS", BY A. ALAN *
* B. PRITSKER, PAGES 243-248. *
*****

```

```

COMMON /QVAR/ NDE,NFTBU(100),NREL(100),NREL.P(100),
1 NREL.2(100),NRUN,NRUNS,NTC(100),PARAM(100,4),TBEG,TNOW

```

```

*****
* THIS PORTION OF THE USER FUNCTION (UF) IS USED TO DETER- *
* MINE WHAT TYPE OF ACTIVITIES HAVE TO BE ACCOMPLISHED *
* WHILE UNLOADING THE FT BARGE. THIS MODEL ASSUMES THAT 4 *
* ETS ARE TRANSPORTED ON THE BARGE AT ONE TIME. IF THERE *
* ARE NO ETS ON THE BARGE THEN THE BARGE IS RETURNED TO *
* PICK UP MORE ETS (UF = 1). IF THERE ARE TWO ETS LEFT ON *
* THE BARGE, THEN THE TRANSPORT STANDS FOR THE FIRST TWO *
* ETS ARE LOADED ON THE BARGE BEFORE ANOTHER FT IS UNLOADED *
* (UF = 2). IF THERE IS ONE OR THREE ETS STILL ON THE BARGE, *
* THEN THE NEXT FT IS IMMEDIATELY UNLOADED (UF = 3). *
*****

```

```

IF (IFN.EQ.1) THEN
  IF (NREL(5).EQ.0.0) THEN
    UF = 1.0
  ELSE IF (NREL(5).EQ.2.0) THEN
    UF = 2.0
  ELSE
    UF = 3.0
  END IF
END IF
RETURN
END

```

```

*****
* THE FOLLOWING IS THE O-GERT CODE USED TO DEPICT THE GRAPH- *
* ICAL MODEL OF THE VAFB SYSTEM. THIS CODE IS USED BY THE *
* O-GERT ANALYSIS PROGRAM TO ANALYSE THE SYSTEM. THE PRO- *
* GRAM ACCOMPLISHES 10 RUNS OF THE SYSTEM, EACH BEING 4015 *
* DAYS IN LENGTH. THE FIRST 365 DAYS OF EACH RUN ARE IG- *
* NORED AND NOT USED FOR CALCULATING THE STATISTICS. THIS *
* IS DONE TO REDUCE THE POSSIBLE EFFECTS OF THE STARTING *
* CONDITIONS. AS AN OUTPUT THE PROGRAM PROVIDES THE RE- *
* SULTS OF THE ANALYSIS, AVERAGED OVER THE 10 RUNS. FOR A *
* DETAILED DESCRIPTION OF THE O-GERT COMMANDS USED SEE *
* "MODELING AND ANALYSIS USING O-GERT NETWORKS", BY ALAN A. *
* B. PRITSKER. *
*****

```

GEN,ANDRUSYSZYN,VAFBOPS,09,27,1982,6,0,0,4015,10,,365,4*

SOU,51,0,1,A*
 VAS,51,2,IN,1*
 ACT,51,51,CO,0.0,1,(9)A2.LE.3*
 ACT,51,1,CO,0.0,2,(9)A2.LE.4*
 SOU,52,0,1,A*
 VAS,52,3,IN,1*
 ACT,52,52,CO,1.0,3,(9)A3.LE.299*
 ACT,52,1,CO,1.0,4,(9)A3.LE.300*
 QUE,1/ETNICH,(10)2*
 RES,1/BARGE,4,2*
 ALL,2,,1,1,1/3*
 REC,3,1,1*
 ACT,3,5,UN,1,5/SHIPVAFB*
 QUE,5/ETVAFB,(10)6*
 RES,2/XPORT,1,8*
 *
 ALL,6,,2,1,5/7*
 QUE,7/WAITSTR,(10)8*
 *
 RES,3/STORAGE,4,6*
 *
 ALL,8,,3,1,7/9*
 REC,9,1,1*
 ACT,9,10,NO,2,6/OFFLOAD*
 REC,10,1,1*
 ACT,10,11,NO,3,7/XPORTFT*
 REC,11,1,1*
 ACT,11,12,NO,3,8/RCVINSP*
 REC,12,1,1*
 ACT,12,13,CO,0.0,9*
 ACT,12,20,CO,0.88,10*
 QUE,13/UTCKOUT,(10)14*
 RES,4/CKOUTCEL,1,14*
 ALL,14,,4,1,13/15*
 REC,15,1,1*
 ACT,15,16,NO,4,11/CKOTPREP*
 REC,16,1,1*
 ACT,16,17,NO,5,12/FTSYSCO*
 REC,17,1,1*
 ACT,17,18,NO,6,13/SECURECO*
 REC,18,1,1*

SOURCE OF FIRST 4 ETS

GENERATE FIRST 4 ETS
SOURCE FOR SUBSEQUENT ETS

GENERATE 300 ETS
ETS WAIT FOR BARGE
ESTABLISHES 4 BARGES
ALLOTS BARGE TO ET

SHIP ET TO VAFB
ET WAITS TO BE UNLOADED
ESTABLISHES THE NUMBER
OF ET TRANSPORTS
ALLOTS TRANSPORT
ET WAITS FOR
STORAGE CELL
ESTABLISHES 4 ET STORAGE
CELLS
ALLOTS ET STORAGE

OFF LOAD ET

TRANSPORT ET TO STORAGE

INITIAL ET INSPECTION

RETURN XPORT TO DOCK
ET WAITS FOR CHECKOUT CELL
ESTABLISHES 1 CHECKOUT CELL
ALLOTS CHECKOUT CELL

PREPARE ET FOR CHECKOUT

CHECKOUT ET SYSTEM

SECURE ET FROM CHECKOUT

REG, 20, 1, 1, F*	
VAS, 20, 1, HF, 1*	
ACT, 20, 21, NO, 7, 15/NOFTINO, (9)A1.EQ.1*	DETERMINE BARGE ACTIVITIES
*	NO FTS ON BARGE
*	LOAD LAST 2 TRANS-
	PORT STANDS
REG, 21, 1, 1, 1*	
ACT, 21, 22, HH, 1, 16/RETARGE*	RETURN BARGE TO MICHOU
FRF, 22, 1, 4, 2*	FREE 4 BARGES
ACT, 22, 23, CO, 0.0, 17*	
STA, 23/BARGEPEL, 1, 1, D, B*	
ACT, 21, 24, CO, 0.0, 18*	
ACT, 20, 24, NO, 8, 19/TWOINETO, (9)A1.EQ.2*	TWO FTS ON BARGE
*	LOAD FIRST 2 TRANS-
*	PORT STANDS
ACT, 20, 24, CO, 0.0, 20/OTHERINO, (9)A1.EQ.3*	1 OR 3 FTS
*	ON BARGE. NO
*	SPECIAL ACT.
FRF, 24, 2, 1, 4*	FREE TRANSPORT
ACT, 24, 25, CO, 0.0, 21*	
STA, 25/XPORTREL, 1, 1, D, B*	
ACT, 18, 26, NO, 6, 22/PREPCO*	PREPARE CHECKOUT CELL
*	FOR NEXT ET
ACT, 18, 28, CO, 0.0, 23/ETTOSTOR*	RETURN ET TO STORAGE
FRFE, 26, 4, 1, 14*	FREE ET CHECKOUT CELL
ACT, 26, 27, CO, 0.0, 24*	
STA, 27/COREL, 1, 1, D, B*	
QUE, 28/ETWAIT, (10)46*	ET WAITS FOR USE
SON, 53, 0, 1*	SOURCE OF ORBITER
ACT, 53, 29, CO, 0.0, 44/GENORB*	GENERATE ORBITER
QUE, 29/ORELAND*	
ACT, 29, 30, NO, 9, 25/SAFEORB*	SAFE ORBITER
REG, 30, 1, 1*	
ACT, 30, 31, NO, 10, 26/TOWOMCF*	TOW ORBITER TO OMCF
QUE, 31/WAITOMCF, (10)32*	ORBITER WAITS FOR OMCF
RFS, 5/OMCFBAY, 1, 32*	ESTABLISHES 1 OMCF BAY
ALL, 32, 5, 1, 31/33*	ALLOT OMCF BAY
REG, 33, 1, 1*	
ACT, 33, 34, NO, 11, 27/OMCFACT*	OMCF ACTIVITIES
QUE, 34/OREWAIT, (10)35*	ORBITER WAITS FOR USE

SFL, 35/ASSYORB, ASM, (7)34, 50*

*

*

*

*

ACT, 35, 36, CO, 0.0, 28*

REG, 36, 1, 1*

ACT, 36, 39, NO, 4, 29/MATEORB*

ACT, 36, 37, CO, 0.0, 30*

PRF, 37, 5, 1, 32*

ACT, 37, 38, CO, 0.0, 31*

STA, 38/OMCFRFL, 1, 1, D, B*

REG, 39, 1, 1*

ACT, 39, 40, NO, 12, 32/PADOPS*

STA, 40/LAUNCH, 1, 1, D, B*

*

*

ACT, 40, 41, NO, 13, 33/MISSION*

QUE, 41/WAITLAND, 0, 0, (7)42*

REG, 42, 1, 1*

ACT, 42, 41, CO, 1.0, 34/DELAYLAND*

*

ACT, 41, 29, NO, 14, 35/LANDOPS*

ACT, 40, 43, NO, 15, 36/SECPAD*

REG, 43, 1, 1*

ACT, 43, 44, NO, 16, 37/REFREPAD*

ACT, 43, 44, NO, 17, 38, SUPPOT REFRB*

REG, 44, 2, 2*

ACT, 44, 45, NO, 18, 39/ASSYSRB*

QUE, 45/SRBWAIT, 1, (10)46*

*

SFL, 46/FTTOSRB, ASM, (7)45, 28*

*

*

ACT, 46, 47, CO, 0.35, 40*

REG, 47, 1, 1*

ACT, 47, 48, CO, 0.0, 41*

PRF, 48, 3, 1, 6*

ACT, 48, 49, CO, 0.0, 42*

STA, 49/FTSTREL, 1, 1, D, B*

ACT, 47, 50, NO, 19, 43/MATEET*

QUE, 50/ASSYWAIT, (10)35*

WHEN BOTH THE ORBITER
AND THE ET/SRB ASSEMBLY
ARE AVAILABLE THEN THE
ORBITER MATING PRO-
CESS IS BEGUN

MATE ORBITER

FREE OMCF BAY

LAUNCH PAD OPERATIONS
LAUNCH ORBITER AND
RECORD TIME BETWEEN
SUCCESSIVE LAUNCHES
ORBITER MISSION TIME
LANDING QUEUE FOR ORBITER

DELAY LANDING IF
STRIP IN USE
LANDING OPERATIONS
SECURE PAD FROM LAUNCH

REFURBISH PAD
REFURBISH SUPPORT FUNC

STACK SRBS ON PAD
SRB ASSY WAITS FOR ET
INITIALLY ONE IN QUEUE
WHEN AN ET AND
SRB ASSY ARE AVAILABLE
THEN ET MATE IS BEGUN
XPORT ET TO PAD

FREE FT STORAGE

MATE FT TO SRB ASSY
SRB/ET ASSY WAITS

 * THE FOLOWING ARE THE PARAMETER SETS USED FOR THE ACTIV- *
 * ITIES USED IN THIS MODEL. THE FIRST NUMBER AFTER THE PAR *
 * IS THE PARAMETER SET NUMBER. PARAMETER SET 1 IS FOR A *
 * UNIFORM DISTRIBUTION. IN THIS PARAMETER SET THE FIRST *
 * PARAMETER IS THE MINIMUM TIME WHILE THE SECOND PARAMETER *
 * IS THE MAXIMUM TIME. THE REST OF THE PARAMETERS ARE FOR *
 * THE NORMAL DISTRIBUTION. THE FIRST PARAMETER IS THE MEAN *
 * TIME , THE SECOND IS THE MINIMUM TIME, THE THIRD IS THE *
 * MAXIMUM TIME, AND THE LAST PARAMETER IS THE STANDARD DE*
 * VIATION. ALL OF THE PARAMETERS ARE IN DAYS. *

PAR,1,,25.0,30.0*	SHIP TIME FOR ET
PAR,2,0.131,0.066,0.195,0.022*	OFF LOAD ET
PAR,3,0.120,0.088,0.153,0.011*	ET XPORT TIME AND
*	ET INITIAL INSPECTION TIME
PAR,4,1.925,1.400,2.450,0.175*	PREP ET FOR CHECKOUT
PAR,5,2.80,2.275,3.325,0.175*	ET CHECKOUT TIME
PAR,6,1.750,1.225,2.275,0.175*	SECURE ET FROM CHECKOUT
PAR,7,0.416,0.088,0.744,0.109*	LOAD ET TRANSPORT
*	STANDS, 0 IN QUEUE
PAR,8,0.214,0.175,0.306,0.022*	LOAD ET TRANSPORT
*	STANDS, 2 IN QUEUE
PAR,9,2.909,1.794,4.025,0.372*	SAFF ORBITER
PAR,10,0.109,0.044,0.306,0.066*	TOW ORB TO ONCF
PAR,11,16.319,10.675,21.963,1.881*	ONCF ACTIVITY TIME
PAR,12,6.847,5.338,8.356,0.503*	PAD OPERATIONS
PAR,13,4.00,2.00,6.00,1.00*	MISSION TIME
PAR,14,0.175,0.044,0.438,0.044*	LANDING OPERATIONS
PAR,15,0.175,0.109,0.241,0.022*	SECURE PAD FROM LAUNCH
PAR,16,4.244,2.275,6.213,0.656*	REFURBISH LAUNCH PAD
PAR,17,3.675,2.888,4.463,0.263*	REFURBISH SUPPORT FUNC
PAR,18,4.374,3.850,4.900,0.175*	STACK SRBS
PAR,19,1.400,0.875,1.925,0.175*	ET MATE TIME
FIN*	

Table XXX. Parameters For VAFB Model

Act. Num.	Activity Description	Dist. Type	Mean		Minimum		Maximum		Standard Deviation	
			Hours	Days	Hours	Days	Hours	Days	Hours	Days
5	Ship ET to VAFB	UN	-	-	-	25.0	-	30.0	-	-
6	Offload ET	NO	1.50	0.131	0.75	0.066	2.25	0.195	0.250	0.022
7	Transport ET	NO	1.375	0.120	1.00	0.088	1.75	0.153	0.125	0.011
8	Receive/Inspect ET	NO	1.375	0.120	1.00	0.088	1.75	0.153	0.125	0.011
10	Return Transport	CO	1.000	0.088	-	-	-	-	-	-
11	ET Checkout Prep	NO	22.000	1.923	16.00	1.400	28.00	2.450	2.000	0.175
12	ET System Checkout	NO	32.000	2.800	26.00	2.275	38.00	3.325	2.000	0.175
13	Secure Checkout Cell	NO	20.000	1.750	14.00	1.225	26.00	2.275	2.000	0.175
15	Load Transport Stands	NO	4.750	0.416	1.00	0.088	8.50	0.744	1.250	0.109
19	Load Barge	NO	2.750	0.241	2.00	0.175	3.50	0.306	0.250	0.022
22	Prep ET Checkout	NO	20.000	1.750	14.00	1.225	26.00	2.275	2.000	0.175
25	Safe Orbiter	NO	33.250	2.909	20.50	1.794	46.00	4.025	4.250	0.372
26	Tow Orbiter to OMCF	NO	1.250	0.109	0.50	0.044	3.50	0.306	0.750	0.066
27	OMCF Activities	NO	186.500	16.319	122.00	10.675	251.00	21.963	21.500	1.881
29	Mate Orbiter	NO	22.000	1.925	16.00	1.400	28.00	2.450	2.000	0.175
32	Pad Operations	NO	78.250	6.847	61.00	5.338	95.50	8.356	5.750	0.503
33	Orbiter Mission	NO	-	4.000	-	2.000	-	6.000	-	1.000
35	Landing Operations	NO	2.000	0.175	0.50	0.044	5.00	0.438	0.500	0.044
36	Secure Pad	NO	2.000	0.175	1.25	0.109	2.75	0.241	0.250	0.022
37	Refurbish Pad	NO	48.500	4.244	26.00	2.275	71.00	6.213	7.500	0.656
38	Refurbish Support	NO	42.000	3.675	33.00	2.888	51.00	4.463	3.000	0.263
39	Stack SRBs	NO	50.000	4.374	44.00	3.850	56.00	4.900	2.000	0.175
40	Transport ET to Pad	CO	4.000	0.350	-	-	-	-	-	-
43	Mate ET to SRBs	NO	16.000	1.400	10.00	0.875	22.00	1.925	2.000	0.175

VITA

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Space Transportation System Space Shuttle Kennedy Space Center Vandenberg AFB Q-GERT	Simulation Network Analysis	
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
<p>The Space Transportation System (STS) is being developed by NASA for NASA, DoD, and commercial use. National Space Policy dictates that the STS become NASA's and DoD's primary means for launching payloads into orbit. Unfortunately, the current flight manifest saturates STS launch rate capability. Therefore, additional operational funding will be required to increase the rate of launch. This funding must be applied to those portions of the system which contribute greatest to increasing the system launch rate. This study presents two methods for determining the system launch rate, identifying the bottlenecks, and developing a</p>		

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20. (cont.) launch enhancement plan. The analytic method is fairly easily and quickly accomplished, using the data provided in the NASA Shuttle Turn-around Analysis Report, while the Q-GERT simulation method gives more accurate estimates of the launch rate capability. Plans are presented to show the facility configurations and flight hardware levels required to achieve various launch rate capabilities at Kennedy Space Center. The capacity of VAFB was determined, but no launch enhancement plan was developed since an increase in the launch rate would require the obvious duplication of most of the facilities. The method presented can be used on data provided in future STARS.

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