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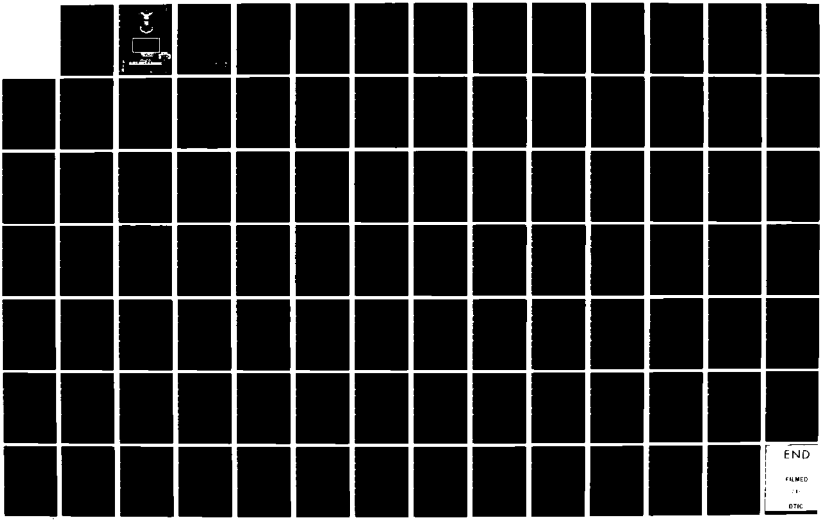

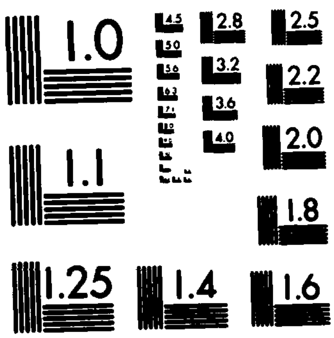

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A Q-GERT ANALYSIS OF THE SPACE
SHUTTLE GROUND TURNAROUND
SYSTEM AT VANDENBERG
AIR FORCE BASE

Steven Graham, Captain, USAF
Terry W. Jones, Captain, USAF

LSSR 21-82

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1. REPORT NUMBER: LSSR 21-82	2. GOVT ACCESSION NO. A123 808
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): A Q-GERT ANALYSIS OF THE SPACE SHUTTLE GROUND TURNAROUND SYSTEM AT VANDENBERG AIR FORCE BASE	5. TYPE OF REPORT & PERIOD COVERED: Master's Thesis
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Steven Graham, Captain, USAF Terry W. Jones, Captain, USAF	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: School of Systems and Logistics Air Force Institute of Technology, WPAFB OH	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: Department of Communication and Humanities AFIT/LSH, WPAFB OH 45433	12. REPORT DATE: September 1982
	13. NUMBER OF PAGES: 80
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Re t)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

PROVED FOR PUBLIC RELEASE: IAW AFR 190-17

LYNN E. WOLAVER
Dean for Research and Professional Development

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WRIGHT-PATTERSON AFB OH 45433

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Space Shuttle
Ground Turnaround
Q-GERT Simulation
Space Operations
Space Logistics

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Thesis Chairman: Rodney C. Byler, Major, USAF

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The efficient ground turnaround of the Space Shuttle is critical to the execution of national policies. Research identified four major subsystems within the Vandenberg Ground Turnaround System; the Orbiter Maintenance Subsystem, External Tank Subsystem, Solid Rocket Booster Subsystem, and Launch Pad Subsystem. A Q-GERT simulation of the Ground Turnaround System was conducted to investigate the system and observe the interactions between the major subsystems. The Q-GERT model simulated the integration of Space Shuttle components to determine the subsystem most sensitive to change. The results indicate the Launch Pad Subsystem is the most critical in the Vandenberg Ground Turnaround System. However, further research is recommended in areas of logistics support, spares availability, and transportation of components.

LSSR 21-82

A Q-GERT ANALYSIS OF THE SPACE SHUTTLE GROUND TURNAROUND SYSTEM AT VANDENBERG AIR FORCE BASE

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirement for the

Degree of Master of Science in Logistics Management

By

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September 1982

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This thesis, written by

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and

Captain Terry W. Jones

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT

DATE: 29 September 1982

Rodney C Byler

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ACKNOWLEDGMENTS

We wish to publicly recognize the patience, faith, and support of our understanding wives, Teresa Graham and Kathy Jones. We also wish to thank our very patient and highly competent typist, Ms. Marianne Ramsey, for her outstanding contribution to this thesis. Finally, we express our gratitude and appreciation to our advisor, Major Rodney Byler. Without his guidance and support, this thesis could not have been completed.

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Chapter 1

INTRODUCTION

By 1988, the United States anticipates the planned Space Shuttle fleet of four Orbiters will be launched at the rate of 24 a year. However, the future demand for Space Shuttle services exceeds launch capacity. Well over 75 percent of the total nonfederal demand for launch services is from the communications sector, and the compound annual growth rate of communications demand is anticipated by the Office of Management and Budget to exceed 24 percent (9:24). The Space Transportation System may not be able to capture all of this satellite traffic because other countries are developing alternative launch capabilities at competitive prices and schedules. For example, development delays in the shuttle program caused Intelsat to give launch responsibility for three satellites to Ariane (9:24). Furthermore, Western Europe's Ariane launch program now receives over 40 percent of its launch orders from outside the European Economic Community (4:13). China and Japan are also developing vehicles capable of launching communications satellites (9:24). In order to satisfy user demands for Orbiter payload capacity and to counter aggressive competition from other countries, a rapid and efficient ground turnaround process for the Space Shuttle becomes imperative.

Projecting the exact number of annual Shuttle flights per Orbiter is, however, impossible (9:25). Projections of future operations can only be made using as a basis the average time allowances of the several parameters that affect launch spacing. Of these parameters, the turnaround process for maintenance and servicing of the many Shuttle components affects projections most (9:25).

An efficient ground turnaround process for the Space Shuttle will be an important factor in the Shuttle's cost effectiveness and competitiveness; faster turnarounds allow more flights, resulting in a lower cost per flight. Currently, the Space Shuttle turnaround facilities at Vandenberg Air Force Base (VAFB) are expected to reach initial operational capacity in 1985 (7:28; 19:44). Even though construction of the facilities has not been completed, the turnaround process itself has been established.

All turnaround operations begin at the runway with the end-of-mission rollout of the Orbiter. The Orbiter will land on a runway 15,000 feet long and 200 feet wide. It will initially be towed to a Safing and Deservicing Facility and from there to an Orbiter Maintenance and Checkout Facility (OMCF).

At the OMCF, the Orbiter Maneuvering System pods will be removed, if necessary, from the Orbiter and sent to the nearby Hypergolic Service Facility for servicing. When maintenance at the OMCF has been completed, the Orbiter will be towed 16 miles to Space Launch Complex-6 (SLC-6) on South Vandenberg. SLC-6 includes launch pad, Launch Control Center, Mobile Service Tower, Umbilical Tower, utilities, storage tanks, and railroad tracks. Here, the flight elements of the Space Shuttle will be joined in the open, a relatively hostile outdoor environment (19:49). Because the task of lifting the Orbiter in gusty wind conditions and trying to attach it to External Tank attach points with very small clearances could limit preparation activities, a Mobile Weather Shelter is being designed to enclose the vehicle during its erection (19:49; 20:51). Doors inside this shelter will allow the Payload Changeout Room to move within it and deliver the payload to the Orbiter.

The large External Tank (ET) will be built in Michoud, Louisiana, and delivered to a dock on VAFB via an ocean barge that passes through the Panama Canal. Each barge is capable of carrying up to four ETs. From the dock, the ETs are towed two miles on individual transporters to a Tank Checkout and Storage Facility (TCF) about a mile from the launch pad. The Launch Processing System in the Launch Control Center will checkout the ET (19:45).

The Solid Rocket Booster (SRB) turnaround begins with water retrieval about 160 nautical miles south of VAFB. At lift off, a recovery ship and a commercial tug will be waiting on station as the SRBs burn out, separate from the ET, and parachute into the ocean (1:100).

The retrieval vessel removes the parachutes and frustums from each SRB and dewaters them. Then each vessel tows an SRB to Port Hueneme, a port located 85 miles southeast of VAFB where facilities are being built to support SRB retrieval.

Once at Port Hueneme, retrieved SRBs will be washed, deserviced, and safed before being disassembled and cleaned. Case segments are packed and sent back to the manufacturer, Thiokol Corporation in Ogden, Utah, for refurbishing and refilling (1:100; 19:47). The structure members are cleaned and transported to a Solid Rocket Booster Refurbishment and Subassembly Facility (SRSF) at VAFB. SRB segments refurbished by Thiokol Corporation are sent directly to the SRSF by rail.

The crane on the Mobile Service Tower at SLC-6 will vertically stack individual SRB segments brought to the launch pad from the SRSF (19:49). A crane located in the Mobile Weather Shelter, along with the crane in the Mobile Service Tower, will be used to erect and mate the ET to the SRBs. The same procedure is then used to erect and mate the Orbiter to the ET. All of these processes will occur within the Mobile Weather Shelter.

Some payloads will be integrated with the Orbiter horizontally in the OMCF. Others will be integrated with the Orbiter vertically at the launch pad (1:100; 19:49). Vertically integrated payloads are processed through the

Payload Preparation Room, transferred to the Payload Changeout Room at the launch pad and then placed into the Orbiter's payload bay.

With the flight elements integrated, the Payload Changeout Room, the Weather Shelter, and the Mobile Service Tower will remain around the stacked vehicle for both access and checkout until the final phase of the launch countdown. At that time they are moved back to their launch positions, the crew enters the Space Shuttle, and the terminal countdown begins. After completing the mission, the Orbiter may land at VAFB and the turnaround process begins anew.

Even though the flow of the ground turnaround process at VAFB has been developed, an accurate and realistic time estimate for turnaround cannot be computed because the functional relationships of the components of the turnaround process are not known.

The lack of a methodology for accurately predicting the time requirements for Shuttle turnaround has possibly been a major contributor to domestic users turning to foreign competitors for launch support. Furthermore, uncertainty about turnaround time could also significantly limit military operations depending on Shuttle launch availability (2:80). A fairly complete model of the turnaround system could be useful to Department of Defense planners in testing the availability of ETs, SRBs, and

Orbiters as well as transport capability, crew size, and other factors associated with a large-scale operation. The many uncertainties involved in the ground turnaround process justify further research into some unknown areas. How many ETs must be available for mating to the Orbiter so that more than one flight set is available at any given time once the turnaround process begins? Can the SRBs be retrieved and refurbished in sufficient time to support a given launch rate? Will the weather at VAFB limit the efficiency of the turnaround process? These questions and a multitude of others should be tested in a model to determine their impact before attempting the ground turnaround process. Additionally, the large expense and manhour requirements of an actual test of the turnaround process, even if possible, can be avoided by using a model.

Many alternatives can be explored in a model that would otherwise be difficult to incorporate in an actual demonstration. For example, closing the Panama Canal or blocking the dock at Port Hueneme is readily accomplished in a model. Time is easily compressed or expanded in a model and resources may be made available or withdrawn from any desired area. Perhaps most important, the application and use of a simulated model assists the experimenter in understanding the problem and gaining insight into his operation.

Problem Statement

The launch and landing turnaround program requirements for the Space Shuttle at Kennedy Space Center (KSC) specify that the time required for turnaround shall not exceed 160 working hours covering 14 calendar days. However, no method has been developed to determine if the tasks required for operational turnaround can be completed within a specified timeframe at VAFB.

Research Objective

The purpose of this research is to develop a model for estimating the time required between Space Shuttle landings and takeoffs to complete a turnaround at VAFB and to enable Space Shuttle management to make the best possible decisions in allocating the resources required to effect an efficient turnaround. The research objective will be met by answering the following questions.

Research Questions

1. What is the structure of the Space Shuttle Ground Turnaround System at VAFB?

2. What are the interactions among the major subsystems of the VAFB Ground Turnaround System?

3. Which of these subsystems are most sensitive to change?

Literature Review

Selection of Vandenberg as a Launch Site. In April 1971, the Shuttle Launch and Recovery Board, consisting of Department of Defense and NASA officials, was established to review potential launch and recovery sites for the Space Transportation System (19:47). Because the original design for the Shuttle system called for both components of the booster-orbiter combination to land like airplanes, new requirements for launch and landing were established. In fact, over 150 contending locations were identified (19:47). However, in March 1972, NASA selected the ballistic, water-recoverable, SRB concept and fully defined the Space Shuttle configuration. Because of the large area required for impact of the SRBs and for possible emergency jettisoning of the large hydrogen-oxygen ET, no suitable inland site could be found which would afford more than just a few acceptable launch azimuths. Thus, board consideration was limited to coastal sites because they afforded many azimuths as well as greater adaptability to changes in the launch program (19:48).

The extensive surveys made by the board restricted site choice to only two locations and both had limitations.

1. Kennedy Space Center could not provide azimuths for polar or sun-synchronous orbits, because southerly

headings would drop SRBs on land and northerly launches would cause the Space Shuttle to overfly heavily populated areas of the United States and Canada (19:47).

2. Vandenberg launch operations could allow increased payload weight and volume available to polar and near-polar orbits (1:97). VAFB's large size and relative isolation mitigate in favor of safety and environmental parameters, and VAFB had many existing facilities and support organizations which could be used to support Space Shuttle operations. However, Vandenberg could not provide easterly launches.

Further investigation of potential Gulf Coast launch and landing sites revealed an area in Matagorda County, Texas, that had the potential to meet most needs of the program. However, a cost analysis showed that constructing and equipping a new site for Shuttle operations would require an investment of $300 million more than the cost of achieving the same capability at KSC and Vandenberg. Space Launch Complex-6 at Vandenberg, for example, included launch pad, Launch Control Center, Mobile Service Tower, Umbilical Tower, utilities, storage tanks, and railroad tracks. Originally constructed to support launch operations of the Manned Orbiting Laboratory, these facilities were never used, but the original launch site preparation was applicable to supporting Space Shuttle operations. Additionally, the cost analysis showed that the savings from operating a single launch site did not overcome this significant differential in initial investment and added costs of phasing in the operations at a new site (19:48).

In summary, the Shuttle Launch and Recovery Board found no economic, no mission, or no operational advantage over the two existing locations. Therefore, in April 1972, the board chose KSC and VAFB as Shuttle launch and landing sites.

Characteristics of the Space Shuttle Vehicle

The Space Shuttle Vehicle is composed of a manned Orbiter, an ET containing the ascent propellants used by the three Space Shuttle Main Engines (SSME), and two Solid Rocket Boosters (SRB). The Orbiter, SSMEs, and SRBs are reuseable while the ET is expendable (21:1).

The Orbiter is comparable in size to a DC-9 aircraft with a length of 122.2 feet, a wing span of 78.06 feet, and a height of 56.67 feet (16:85; 21:1). The cargo bay is 15 feet in diameter, 60 feet long and accommodates a payload of up to 65,000 pounds. Returning to ground, the Orbiter accommodates up to 32,000 pounds of cargo. The Orbiter normally has a crew of two but can carry up to six crew members or passengers (21:1). The Main Propulsion System (MPS) which is used during launch is in the aft end of the Orbiter while the Orbital Maneuvering Subsystem (OMS) provides thrust for initial orbit insertion, orbit change, rendezvous, and return to earth. The Reaction Control

Subsystem (RCS) is contained in the two OMS pods and in the nose section of the Orbiter. The RCS and the Orbiter's control surfaces provide altitude control on reentry (21:4).

The ET is 27.5 feet in diameter, 154.2 feet long and contains the propellants for the SSMEs. The ET contains 1.55 million pounds of propellant (liquid hydrogen fuel and liquid oxygen oxidizer) at liftoff. The liquid hydrogen and liquid oxygen are in separate aluminum alloy tanks that are butt-fusion-welded together to provide reliable sealed joints (21:4). The aluminum inter-tank structure is braced in a stabilizing frame and a one-inch layer of foam insulation is sprayed on the ET. All fluid controls and valves for the Main Propulsion System, except for the vent valves, are located in the Orbiter to minimize throwaway costs. After the required ascent trajectory is attained, the ET separates from the Orbiter and then breaks up as it falls ballistically into the ocean.

The three SSMEs are used during Shuttle ascent. Each of the engines is approximately 14 feet long with a nozzle nearly 8 feet in diameter. Each engine has a sea level thrust of 375,000 pounds and a vacuum thrust of 470,000 pounds (21:4). The engines can be gimballed for flight control during ascent and are fueled by the propellants in the ET. The SSMEs, which may be the most advanced liquid propellant engines ever built, feature high performance, variable thrust, and long life. A built-in computer controls ground checkout, inflight diagnoses, and controls engine operation from startup through shutdown (8:64).

Two SRBs burn in parallel with the Main Propulsion System to provide initial ascent thrust to lift the Shuttle, weighing up to 4.4 million pounds, to an altitude of 27.5 miles. Primary components of the SRBs are the Solid Rocket Motor, forward and aft structures, operational flight instruments including separation and recovery avionics, separation motors and pyrotechnics, and recovery parachutes (21:4). Each SRB weighs approximately 1.289 million pounds and produces 2.65 million pounds of thrust at sea level. The SRBs are released from the Orbiter by pyrotechnic separation devices. Then eight booster separation motors on each SRB separate the SRBs from the ET. Descent is aided with a ribbon drogue parachute and ribbon main parachutes on each SRB (21:5). A pictorial representation of the Space Shuttle Vehicle is shown in Figure 1 (18:49).

<u>Computer Simulation of the Turnaround Process</u>. Simulation according to Shannon, is the process of designing a model of an existing system, or one capable of being brought into existence, and experimenting with the model to either understand the purpose of the system or to evaluate various strategies for operating the system (17:12). Since the proposed VAFB Shuttle turnaround process is basically a system, comprised of a series of queues, that begins with the landing of the Shuttle and ends with completion of a

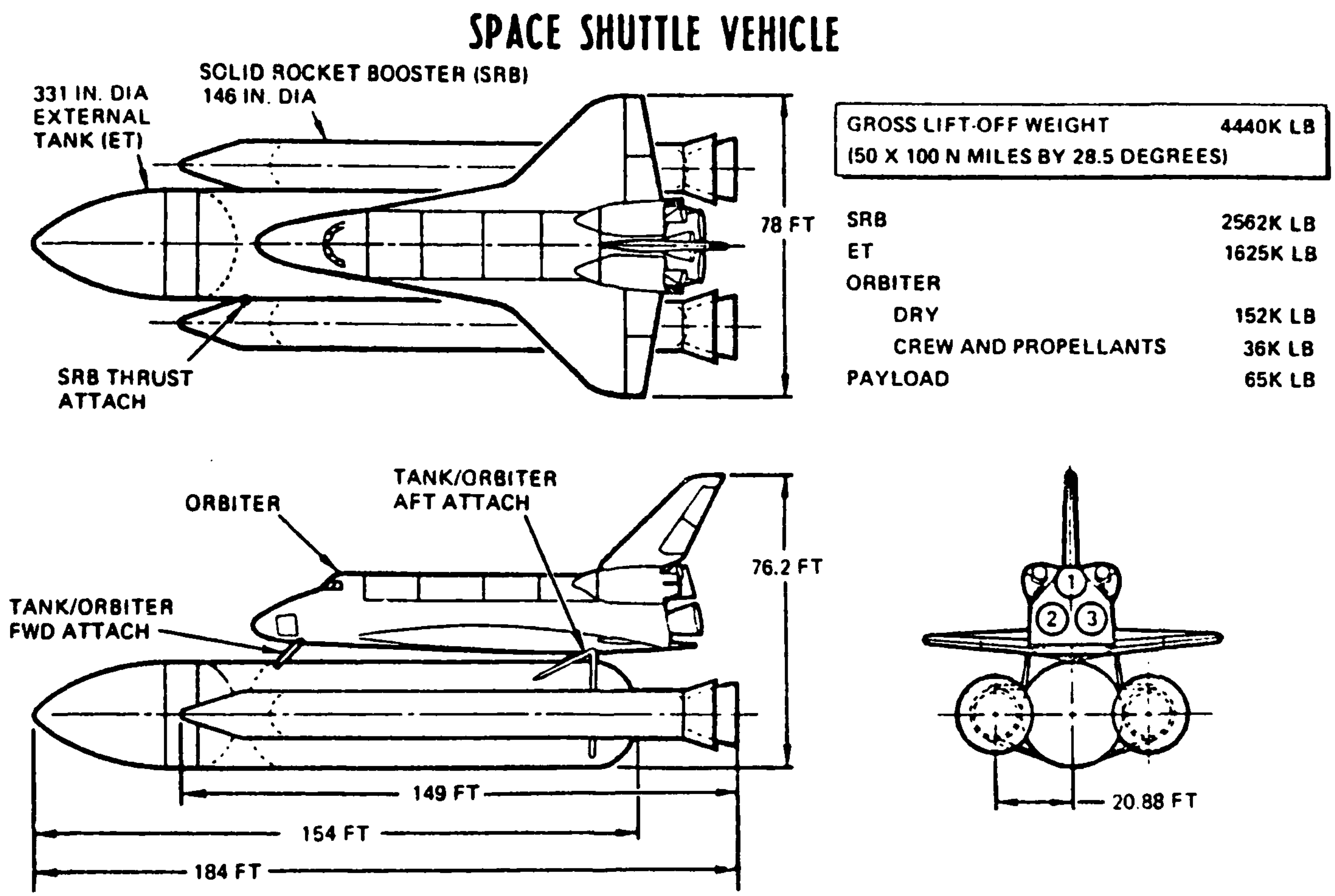


Figure 1

Space Shuttle Vehicle

launch, a model of this system will provide decision makers a method of controlled experimentation in a situation where it is not possible to explore many types of alternatives in real life (17:6). Computer simulations can be designed to represent a dynamic, real-world situation which can be manipulated to approximate the effect of a variable on the operation of the system. When using a model, changes in the turnaround system can be easily implemented when, in the real system, the identical changes would be impractical or impossible to institute. Additionally, using a model, the time frame of the ground turnaround process can be compressed from a few weeks into a few minutes.

The Ground Turnaround System is a procedural system where emphasis is placed on improving performance through procedural changes or design changes regarding scheduling, sequencing, distribution, allocation, layout, and similar functions. Unfortunately, modeling a procedural system is more difficult than a physical system because few fundamental laws are available; procedures are difficult to describe and represent; policy inputs are difficult to quantify; many significant elements of the system occur at random; and human decision making is an integral part of such systems (14:1). However, a network model called Q-GERT was developed around 1966 by Dr. A. B. Pritsker to study the procedural aspects of systems. Designed to model queueing systems in graphic form, Q-GERT can be used with project management, risk analysis, and decision making for solving procedural problems (14:viii). Q-GERT procedurally breaks a system down into its basic, significant elements, analyzes and describes the elements, integrates the elements in a network model of the system, and allows system performance assessment through evaluation of the network model. Moreover, Q-GERT is easily modified to embellish a basic model to build more detailed and complex models. Because it is flexible, procedurally oriented, and available, Q-GERT will be used to simulate the VAFB Ground Turnaround System in this research effort. A summary of basic Q-GERT symbols is provided in Appendix A (14) to explain the symbols used in network modeling.

Plan of Presentation

In Chapter 2, the VAFB Ground Turnaround System and the interrelationships of its subsystems will be discussed in greater detail. Additionally, Chapter 2 will also provide more specific details on the Q-GERT technique and its application to translate the real Ground Turnaround System into an experimental model.

Chapter 3 discusses the methodology of translating the VAFB Ground Turnaround System into a Q-GERT network as well as the assumptions necessary to simplify the network of subsystems. This description of the Q-GERT model will be followed by a discussion of model validation and sensitivity analysis.

In Chapter 4, simulation runs of the Q-GERT model will be discussed along with manipulation of model parameters to determine the significant factors involved. Additionally, the results of the simulation runs and the analysis of the statistics compiled on the run of data elements will be presented.

Finally, Chapter 5 will summarize the answers to our research questions, discuss limitations posed by assumptions, and provide recommendations for further research.

Chapter 2

SYSTEM DEFINITION AND Q-GERT APPLICATION

In order to find an acceptable solution to a problem, one must first know what the problem is. An important part of problem formulation is the definition of the system to be studied (17:26). The following section is a detailed description of the VAFB Ground Turnaround System, its four major subsystems, and their interrelationships.

The VAFB Ground Turnaround System

A continuous supply of mission-ready Orbiters to support commercial, tactical, and strategic launches from VAFB hinges on the availability of Space Shuttle components and on the effectiveness of ground maintenance operations. Without readily available components such as ETs and SRBs, there is no feasible way to rapidly prepare an Orbiter for launch. Similarly, any limiting factors that affect Orbiter or payload preparation will also restrict launch capacity. One such crucial component of the overall Ground Turnaround System is the subsystem of Orbiter Maintenance.

The Orbiter Maintenance Subsystem. Orbiter Maintenance begins on the runway at VAFB with delivery of the Orbiter by a Shuttle Carrier Aircraft or with a normal end-of-mission landing of the Orbiter (19:44). Upon landing, the Orbiter is towed to a Safing and Deservicing Facility (SDF). Here, the Orbiter is supplied with power and cooling to gradually dissipate the heat load of reentry (1:98). The propellant and cryogenic systems of the Orbiter are deserviced and purged as required while ordnance devices are safed. Visual inspections of the Orbiter are made and the on-board computer data are examined to determine if any need exists for maintenance actions. Also, while in the SDF, the Forward Reaction Control System can be removed for off-line maintenance. Finally, the Orbiter is towed to the Orbiter Maintenance and Checkout Facility (OMCF).

The OMCF is a hangar of 40,000 square feet that will house initial post-recovery Orbiter Maintenance operations. In this facility, two Orbiters can be housed at the same time. Surrounding the OMCF is a facility of 121,000 square feet that houses the supported payload operations areas (1:98). The OMCF contains a complex system of fixed and moveable platforms which provide ready access to every part of the Orbiter. Inside the OMCF, routine servicing, inspection, and scheduled maintenance can be performed on the tires, landing gear, crew module, electrical systems, hydraulics and flight controls, and life support systems. At the same time, any damaged tiles in the Thermal Protection System will be repaired or replaced, the Hypergolic Propulsion Modules can be removed or replaced, and on-board equipment and mission-particular hardware can be removed or replaced (1:98). While the Orbiter is in the OMCF receiving maintenance, payload operations also commence.

In the OMCF, the Orbiter's payload bay is surrounded by a solid enclosure to ensure stringent cleanliness, environmental control, and security even when the payload doors are open. Returned payloads, such as retrieved satellites, can be lifted out of the bay with a 70-ton bridge crane. The payload is then transferred to a transporter or to a deservicing area where it is rotated to a vertical position and installed in a deservicing cell to allow removal of propellants, safing, destacking, or any other operation necessary to prepare the payload for transport from the OMCF. Any payloads requiring horizontal installation are received and installed at the OMCF (1:98). Once maintenance is completed and the appropriate payload has been installed, the Orbiter is towed to Space Launch Complex 6 (SLC-6) for integration with other components of the Space Shuttle.

<u>The External Tank Subsystem</u>. The dimensions of the ET limit the transportation modes capable of moving it from the manufacturer, Martin Marietta Corporation in Michoud, Louisiana, to South VAFB. The only feasible mode currently envisioned is that of sea-going barges capable of carrying four ETs at once. These barges will pass through the Panama Canal and arrive at a dock on the southernmost point

of VAFB. Each ET is individually transported about one mile to the Tank Checkout and Storage Facility (TCF) which is capable of storing up to five ETs in four storage cells and one checkout cell (1:98; 19:98). The tanks are stored and monitored until they are required. Then the ET is checked to ascertain its readiness for flight. As the launch preparation stage requiring an ET is reached, the ET is transported to SLC-6 for checkout by the Launch Processing System in the Launch Control Center.

The Solid Rocket Booster Subsystem

The SRB subsystem is initiated when the SRBs are removed from the ocean south of VAFB. Vandenberg will employ a single dedicated vessel, plus a commercial tug leased as required, for SRB retrieval. The retrieval vessel, staffed by a specially trained crew, will be equipped to recover parachutes and the two SRB frustums, dewater both SRBs, and tow one SRB. The tug will be used as a search vehicle and to tow the second SRB (19:45).

When the SRBs land in the ocean after launch, the tug will position near the more distant one. The retrieval vessel will approach the nearer SRB and recover its drogue parachute, frustum, and main parachute. The SRB is then dewatered with the use of a nozzle plug and blowdown system, and towed near the tug. The tug attaches the serviced SRB and tows it to Port Hueneme, a port located 85 miles southeast of VAFB where facilities are being built to support SRB retrieval. The retrieval vessel will then gather the parachutes and frustum of the second SRB, dewater it, and tow it to port. The first SRB should be on dock at Port Hueneme within 40 hours after launch and the second SRB should arrive nine hours later (19:46).

Once at Port Hueneme, retrieved SRBs will be washed, deserviced, and safed before being disassembled and cleaned. Case segments are packed and shipped back to the manufacturer, Thiokol Corporation in Ogden, Utah, for refurbishing and refilling. The parachutes, which are handled separately, are moved directly from the retrieval vessel to a Parachute Refurbishment Facility at VAFB (19:47). All structural members of the SRBs are cleaned, packed, and transported to an SRB Refurbishment and Subassembly Facility (SRSF) at VAFB.

The SRSF, a facility of 121,000 square feet, provides room for storage and preparation of the SRB case segments when they arrive at VAFB by rail from the manufacturer. The other SRB components are also checked out and repaired in the SRSF. Transport of the SRBs to SLC-6 is the initial step of launch pad operations.

The Launch Pad Subsystem

SLC-6 uses an Integrate-On-Pad Concept where each element of the vehicle is sequentially brought to the launch pad, stacked, and integrated on the pad (1:99). A massive Launch Mount supports the Space Shuttle on the launch pad.

This Launch Mount has three large ducts to carry away the exhaust fumes of the SSMEs and the SRBs.

The SRBs are the first Space Shuttle components to be stacked on the Launch Mount after they arrive from the SRSF. Next the ET is transported from its Storage and Checkout Facility to the Payload Changeout Room (PCR) at the launch pad. The ET is attached to a strongback which is attached to the PCR by a hinge on the bottom and a cable on top. The ET and strongback are then rotated to the vertical position on the face of the PCR and lifted into position (1:99). The PCR is then moved on its rails to the Launch Mount where the ET is put into place and mated with the SRBs. The ET is released from the strongback and the PCR withdraws from the Launch Mount to repeat the same operation with the Orbiter, mating it with the ET.

Payload operations at SLC-6 are based on a Factory-to-Pad concept where payloads that do not require horizontal installation in the OMCF are delivered to the Payload Preparation Room (PPR) at SLC-6. The PPR contains three checkout cells that allow simultaneous prelaunch processing of three different cargos. In these cells, limited checkout and assembly operations can be conducted on the payloads while the Orbiter is being prepared on the launch pad (1:100; 19:49).

When ready for integration with the Orbiter, the payload is moved out of its preparation cell. It is lifted into the PPR tower where the Payload Ground Handling Mechanism (PGHM) is attached to the payload and, with the payload, is transferred to the PCR. The PCR and the PPR interface to transfer the PGHM with the payload as an entity into the PCR. The PCR moves to the launch pad where it rests against the Orbiter. The PGHM transfers the payload into the Orbiter's payload bay. Then the Orbiter/payload physical interface is checked and hazardous servicing operations, if necessary, are completed (19:50). The Orbiter's payload bay doors close, the PCR doors close, and the PCR withdraws from the Orbiter, though it remains at the pad as an access until final countdown. Launch of the Space Shuttle initiates the launch pad refurbishment process and recovery of the SRBs. After completion of the mission, return of the Orbiter to VAFB generates another cycle of the Ground Turnaround System. A pictorial representation of the VAFB Ground Turnaround System is shown in Figure 2 (10:8).

Q-GERT Application

Q-GERT employs a network methodology in which a branch represents an activity that involves a processing time or a delay in a process. Nodes are used to separate branches and to represent milestones, decision points, and queues (14:3). Combined, these branches and nodes make up the Q-GERT network. Through the network flow transactions which may represent physical assets, information, or a combination of these elements. In the network representing

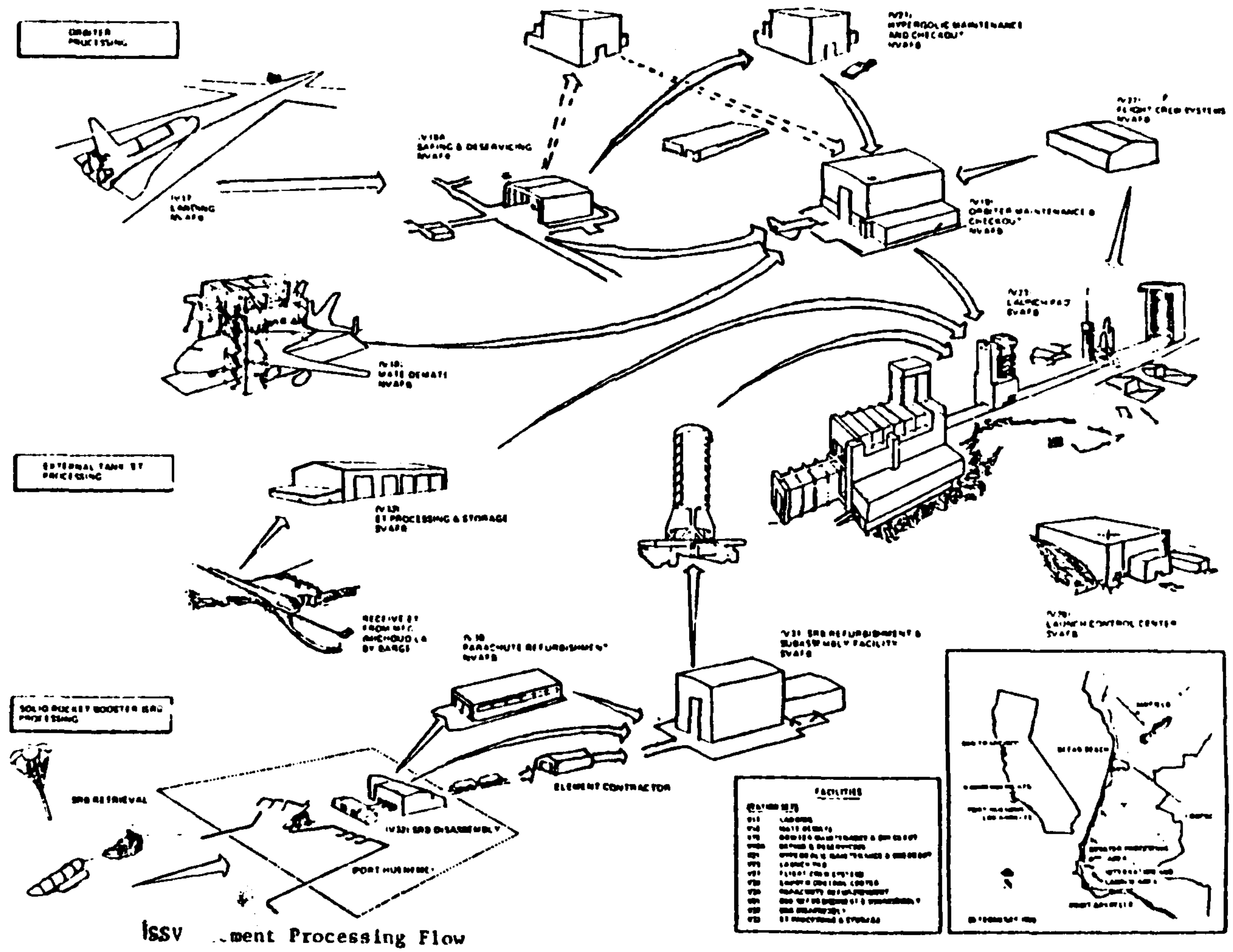


Figure 2

VAFB Ground Turnaround System

the VAFB Ground Turnaround System, transactions represent the components of the Space Shuttle as they are processed through refurbishment and checkout facilities. Activities can be used to represent servers of a queueing system and Q-GERT networks can be designed to model sequential and parallel service systems (14:4). In the VAFB network, for example, the OMCF is represented by an activity that limits service to only two Orbiters at one time. Additionally, the VAFB network is developed to model simultaneous processing of the Orbiter subsystem, the ET subsystem, and the SRB subsystem. In essence, a Q-GERT network is a graphical representation of a process and the flow of transactions through the process (14:18).

Transactions can be assigned attributes that allow the modeler to distinguish between individual transactions of the same type or between transactions of different types. In the VAFB Ground Turnaround System, for example, attributes are assigned to the Orbiter to determine if a payload is loaded horizontally or vertically.

The passage of time is represented in a Q-GERT network by a branch. Thus, the arrival of a transaction into the system, such as the arrival of the Orbiter at VAFB, can be modeled by a branch representing time between successive arrivals. Q-GERT allows the interaction between elements as either deterministic or probabilistic. Parameters are established for each activity in the model of the system where each parameter represents either a constant service time or a specified probability distribution. For example, the time required to transport the Orbiter on the road from the landing area to the SDF has a constant travel time assigned because the road has a minimum risk of closure by weather conditions. On the other hand, the time required to integrate Space Shuttle components for the launch may be subject to wide variances due to weather conditions, availability of components, launch pad refurbishment, or other probabilistic factors. The designers of the model determine the probability distribution of the given activity and calculate or estimate a mean service time and standard deviation or a mode service time with an accompanying optimistic and pessimistic service time (14:27).

Q-GERT allows for an accumulation of transactions into queues when the queueing system provides a limited number of servers. It also permits the modeler to establish queue selection rules, server selection, or both to decide which transactions will be accommodated first when a server becomes available. Q-GERT also allows balking of a transaction, that is, the transaction does not continue to seek service from a server whose queue is full (14:33). These selection options of Q-GERT allow the modeler to assign service priorities to transactions in any order desired.

Q-GERT allows the modeler to choose a single run or multiple runs of a simulation based on time constraints or on a predetermined number of transactions reaching the end of the network. The most common way to start a simulation model is when the system is clear of activity with no transactions in the network. However, this is usually an atypical situation in the real world. To reduce the bias of this initial transient period, the data from the initial period of the run are excluded.

The Q-GERT Analysis Program uses simulation techniques to provide the modeler with statistical information based on the simulation of his network model. The simulation begins with arrival of a transaction at a source node. At each source node, a transaction is marked and then routed through the network according to the branching characteristics prescribed to the source node (14:53). The time required to perform the activity associated with the selected branch is randomly determined by the probability distribution assigned to the activity. An event which correlates to the arrival of the transaction at the end of the activity is scheduled and recorded on an event calendar.

When all source nodes in the network have been considered, time is advanced to the next event on the event calendar, and the type of node the transaction advances to is considered. If the node is not released, that is, it requires more incoming transactions, then time is advanced to the next event time on the event calendar. If the node is released, statistics are collected if necessary, marking is performed if necessary, and the transaction is routed along through the network to the next node according to the branches from the completed node. For each branch selected, the transaction is scheduled to arrive at the next node at the current time on the event calendar plus the activity time. After all of the branches have been selected, the clock time is advanced to the next event on the event calendar and the process continues.

When a transaction arrives at a sink node, a check is made to see if the simulation run is finished. If not, the process continues. If the run is finished, statistics for one run of the simulation are computed and recorded. Additionally, each time an event is taken from the event calendar, the time for the event is compared to the total time of the run (14:54). Because of the Q-GERT Analysis Program was designed to collect statistics over a set of runs, by comparing the variability of average values for a transaction over a multiple of simulations, estimates of the standard deviations of the averages can be obtained.

The statistics provided by the Q-GERT Analysis Program include the average number of transactions in the queues, their average waiting times, and the maximum and minimum numbers of transactions in the queue during a simulation run. Other statistics provided are the fraction of time that a server is busy, the longest consecutive period of time that a single server is busy or idle; and, if an activity is used to represent multiple servers, the maximum number of busy and idle servers (14:71).

Q-GERT is flexible in allowing the modeler to use either a single or multiple server to represent a service activity. For example, the OMCF could be represented by a single server with only one facet of the Space Shuttle integration process being accomplished at a time creating a possible bottleneck, or as a multiple server allowing identical tasks to be accomplished simultaneously. Statistics are also provided at the statistics node at the end of the VAFB ground turnaround model which represents launch of the Space Shuttle. The release of this statistics node is of primary interest since the statistics collected here reflect the length of the turnaround process. Other statistics will help analyze potential bottlenecks or other problem areas where surplus assets have accumulated.

In this chapter, the four major subsystems in the VAFB Ground Turnaround System have been discussed in detail along with their representation using Q-GERT techniques. Chapter 3 will discuss the assumptions necessary to simplify the model, the translation of the VAFB Ground Turnaround System into a Q-GERT model, and validation and sensitivity analysis of the model.

Chapter 3

METHODOLOGY

Having specified the goals and objectives of the research study and having defined and elaborated on the interactions of the subsystems of the VAFB Ground Turnaround System, the current objective is to construct a model of the real system that neither oversimplifies the system nor makes it so detailed and complex that the significant relationships of the system are lost in a myriad of detail. When designing a simulation model, the modeler must make certain assumptions in order to translate a complex system into a model. These assumptions aid in gathering data regarding the inputs and outputs of the real system as well as information about the components of the system and the relationships between them (17:27). In this manner, the complexity of the real system is reduced to a level which can be defined, categorized, and manipulated as the modeler desires. The following sections discuss the assumptions made concerning the VAFB Ground Turnaround System and subsystems, describe the working model, and discuss the methods of analysis used in this study.

Assumptions Concerning the VAFB Ground Turnaround System

The first major assumptions concern the construction of facilities at VAFB. For the purpose of this model, it is assumed that all facilities comprising the VAFB Ground Turnaround System have been completed and are operational. Additionally, the assumption is made that despite current housing shortages in the VAFB area, sufficient manpower has been recruited by shuttle and support contractors to operate shuttle launch facilities (3:22). Furthermore, it will be assumed that all shuttle operations are centered at VAFB, exclusive of KSC. All Orbiters, SRBs, and ETs are dedicated to VAFB launch operations.

Time, as represented in the model, is in days, that is, in units of 24 hours each. It was not the purpose of the modelers to determine manpower requirements or work schedules, so time units do not consider holidays, weekends, or number of shifts. Once the amount of time necessary to complete a task is determined, management should decide the degree of urgency to be assigned.

The times required to perform activities in the VAFB Ground Turnaround System are often represented in the model by a uniform distribution. The uniform density function specifies that every value between a minimum and maximum value is equally likely. The use of this distribution implies a complete lack of knowledge on the part of the modelers concerning the time to perform an activity other than that it is between a minimum value and a maximum value (14:197). The uniform distributions used in this model were derived from the Shuttle Turnaround Analysis Report (STAR) of turnaround data at KSC (12:8.6-8.8) because no similar data have yet been derived from VAFB operations.

Another assumption concerns the percentage of Orbiters that return from a mission carrying a payload. In designing this model, the assumption is made that 20 percent of returning Orbiters will carry a payload and 80 percent will not. Maintenance priority in the OMCF is given to those Orbiters with payloads to be removed.

Finally, the model is based on the assumptions that payloads are always available so that no maintenance activity or mission will be delayed by waiting for assembly or arrival of a payload.

Assumptions Concerning the Orbiter Maintenance Subsystem

The entire population of Orbiters is considered to be based at VAFB and dedicated specifically for VAFB launch support. All Orbiters return to VAFB, either by normal end-of-mission landing or by Shuttle Carrier Aircraft. A primary maintenance-related assumption is that Orbiters return without excessive damage that would render a craft permanently inoperable. Each Orbiter will complete checkout in the SDF before being towed to the OMCF, where only two Orbiters can be serviced at the same time. Orbiters remain in the OMCF until they are ready to be mated to the other Shuttle components on the launch pad. This assumption disregards the time actually spent in towing the Orbiter from the OMCF to the pad.

A factor of complexity in this system is whether or not sufficient supplies, parts, and equipment are available to support Orbiter maintenance. To reduce this complexity, this model considers logistical support problems to be nonexistent.

Assumptions Concerning the External Tank Subsystem

The first major assumption required for dealing with the complexity of this subsystem concerns the number of ETs to be shipped. Since the ocean-going barges that will transport ETs from Michoud, Louisiana to VAFB have a capacity of four, the modelers assume that no barges will depart Michoud without a complete cargo. However, because the TCF at VAFB has storage capacity for five ETs, the assumption is made that one ET is already in place at VAFB. In addition, it is assumed that no shipment of ETs will be sent from Michoud until all four ETs on the barge can be stored.

The final assumptions for this subsystem deal with weather conditions and the international political environment. The modelers assume that the transit time for a barge to travel between Michoud and VAFB will be uniformly distributed between 14 and 21 days. However, assumptions are made that these barges encounter no significant weather delays during their trip. Furthermore, since the route includes travel through the Panama Canal, the model presumes that no obstacles exist, whether political, military, or environmental, to preclude prompt passage through the canal.

Assumptions Concerning the Solid Rocket Booster Subsystem

In this model, storage capacity of the SRSF at VAFB is assumed to be limited to storage of two pairs of SRBs. For the purpose of the model, it is assumed that SRB recovery after launch of the Shuttle is not adversely affected by heavy seas or weather. Since Thiokol Corporation in Ogden will refurbish SRBs as well as manufacture them, the model presumes that an SRB that cannot be refurbished will immediately be replaced by a new SRB. This assumption permits a continuous flow of SRBs between VAFB and the manufacturer.

Once SRBs are returned from Ogden to the SRSF at Vandenberg, the model assumes no shortage of parachutes or other components necessary to reassemble a functional SRB.

Finally, the modelers assume that adequate transportation facilities are available to ship SRB components from VAFB to Ogden and to ship refurbished or new SRBs from Ogden or KSC to VAFB. Therefore, no transportation delays will be experienced in either direction.

Assumptions Concerning the Launch Pad Subsystem

These assumptions are all that remain before construction of the model. The launch pad subsystem is the means for combining the activities of the other subsystems to derive and launch a functional space shuttle.

Weather conditions are a parameter that constrains the launch of the space shuttle. It is assumed that weather conditions will cause delays in ten percent of the launches from VAFB. Once a launch has been delayed, the process of deservicing and reservicing the stacked space shuttle will prevent a rescheduled launch for at least 48 hours.

Upon completion of the launch sequence, the model assumes no catastrophic occurrences that destroy any recoverable portion of the space shuttle, launch pad, or SLC-6 facility. The duration of space shuttle mission is assumed to last seven days (5:100). Pad refurbishment, assumed to require approximately five days, begins immediately after launch, as does SRB recovery (21:8.49).

This concludes the major assumptions used to translate the overall VAFB Ground Turnaround System into this model. The following section contains a detailed description of the model which is graphically represented, by subsystem, in Figures 3, 4, 5, and 6.

Description of the Orbiter Maintenance Subsystem

The Orbiter Maintenance Subsystem, as shown in Figure 3, is designed to model the maintenance activities necessary to maintain up to four Orbiters in the system from landing through preparation for mating with the SRBs and ET on the launch pad. At the beginning of each simulation run, source node 1 generates up to four Orbiters, this generation being regulated by attribute 1. Each Orbiter transaction is routed to regular node 2 which represents arrival of the Orbiters at VAFB. At node 2, each Orbiter transaction is marked so that interval statistics for each transaction can be collected at launch. The interval between node 2 and queue node 3 represents normal landing procedures.

Queue node 3 represents Orbiters that are awaiting movement to the SDF. At allocate node 4, allocation of resource 1, capacity in the SDF, is made. If the SDF is full, waiting Orbiters remain in the queue awaiting service. If the SDF is empty, the Orbiter that has been waiting longest enters queue node 5, which represents the service activities in the SDF. After SDF servicing, the transaction is routed to probabilistic regular node 6. This node randomly routes the 20 percent of returning Orbiters that require payload removal to queue node 7. The remaining 80 percent of Orbiters that return without a payload are routed to queue node 8. The transactions waiting in either queue

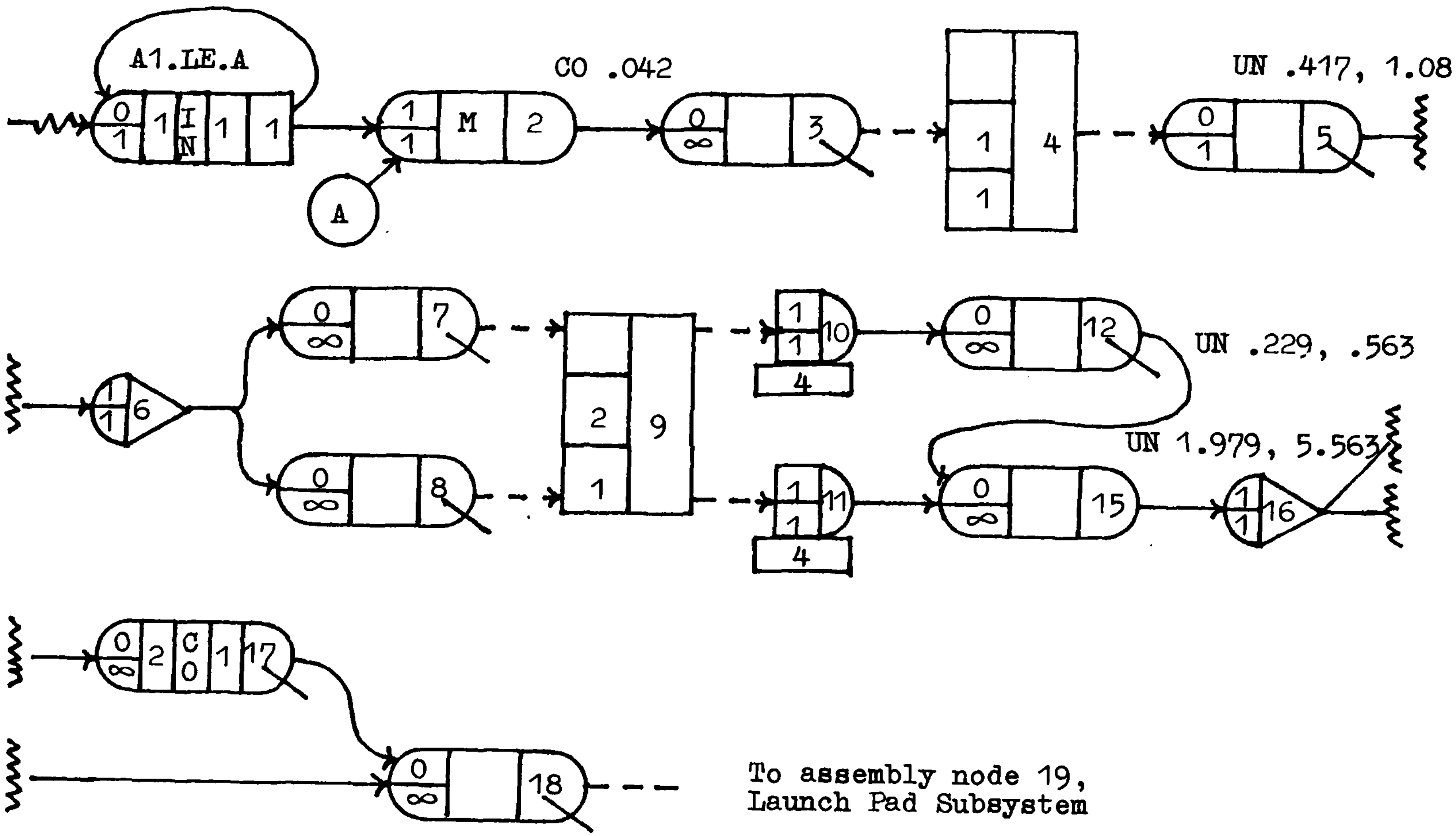


Figure 3

Orbiter Maintenance Subsystem Model

node 7 or 8 represent an Orbiter that has completed SDF service but is waiting for one of the two OMCF service bays.

Allocate node 9 represents the allocation of one unit of resource 2, OMCF capacity. A transaction routed to free nodes 10 or 11 represents the movement of an Orbiter from the SDF to the OMCF, thus freeing the SDF to receive another Orbiter. Orbiters requiring payload removal are routed to queue node 12 where up to two Orbiters can be downloaded. Unloaded Orbiters and Orbiters that return without payloads are routed to queue node 15 for scheduled Orbiter maintenance.

After completion of scheduled maintenance, Orbiter transactions are routed to probabilistic node 16. Here 50 percent of the Orbiters requiring loading of payloads are routed to regular node 17, and 50 percent of the Orbiters requiring vertical loading are routed to queue node 18. At node 17, attribute 2 of each entering transaction is given a value of one to represent that the Orbiter payload has already been loaded.

After determining if payloads are to be loaded horizontally or vertically, Orbiter transactions are routed to queue node 18 where Orbiters wait in the OMCF until it is time for them to be integrated on the launch pad with the SRBs and ETs.

Description of the External Tank Subsystem

The ET subsystem model, as shown in Figure 4, is designed to represent ET operations from generation of the ETs at the manufacturers until their integration with the SRBs on the launch pad.

The ET subsystem begins at source node 41 which represents the generation of four ETs at the Martin Marietta factory in Michoud, Louisiana. Furthermore, this node allows for the continued generation of additional ETs throughout the simulation run. After generation, ET transactions are routed to queue node 42 to await shipment by ocean-going barge to Vandenberg. Allocate node 43 allocates four units of resource 4, barge and TCF capacity. This technique allows only four ETs to be shipped at one time and never allows more ETs to arrive at VAFB than can be stored in the TCF.

Regular node 44 represents the shipping of ETs and regular node 45 represents the arrival of ETs at VAFB. The interval between these nodes logically represents the time required for ocean passage and transiting of the Panama Canal. Queue node 46 represents the ET Storage and Check-out operations associated with the TCF. After an ET is checked out, it is routed to queue node 47 where it awaits integration with a set of SRBs at SLC-6.

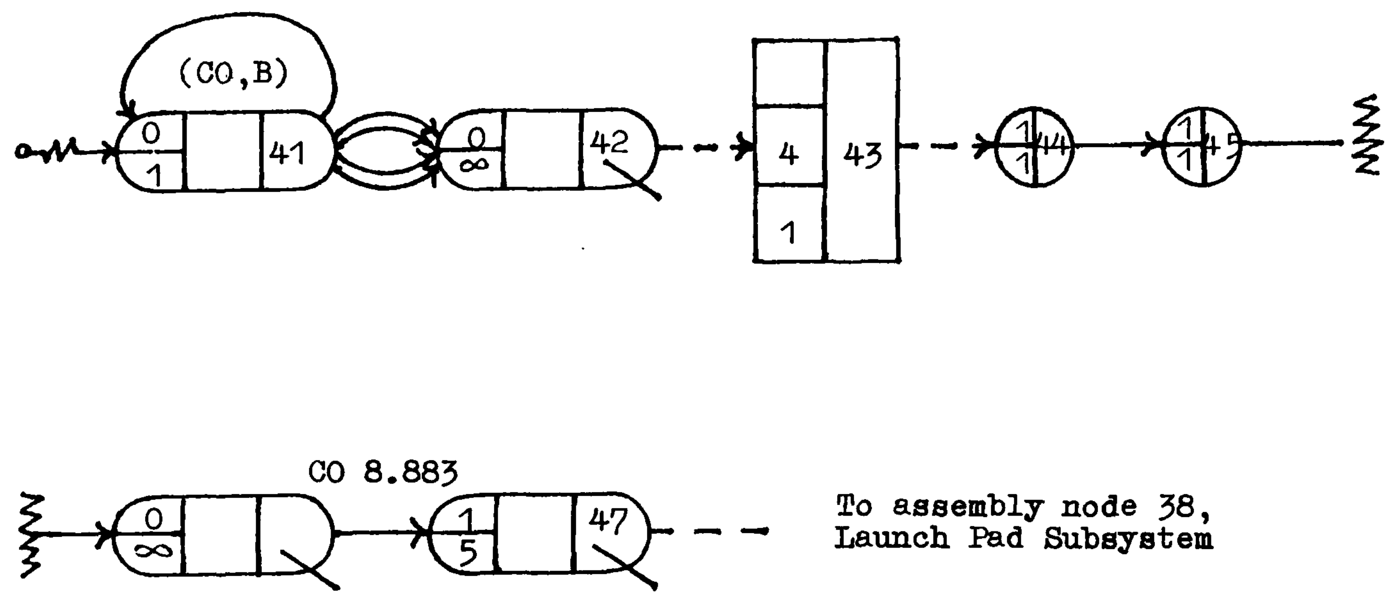


Figure 4

External Tank Subsystem Model

Description of the Solid Rocket Booster Subsystem

The SRB subsystem model shown in Figure 5 is designed to represent SRB operations from recovery of SRBs after launch to refurbishment at the manufacturer and ultimately to stacking of SRB components at SLC-6. All transactions in this subsystem represent a pair of SRBs.

The SRB subsystem begins at regular node 26. The node represents the beginning of SRB recovery operations immediately after launch of the Space Shuttle. Completion of SRB recovery is realized by arrival of SRB transactions at queue node 27. Node 27 represents the safing, deservicing, and preparation of spent SRB case segments for shipment to the manufacturer that occurs at Port Hueneme.

The deservicing process ends as SRB transactions arrive at regular node 28 which represents the shipment of SRB segments to Thiokol Corporation in Ogden, Utah. The arrival of SRB transactions at queue node 31 represents the arrival of these segments at the Thiokol factory where SRB case segments are refurbished or new SRBs are generated to replace them. Source node 50 generates the desired number of SRBs in the VAFB Ground Turnaround System and routes them to queue node 51. The generation of SRBs is regulated by use of attribute 3. Either the refurbished SRB case segments or a new pair of SRBs are routed to queue node 51

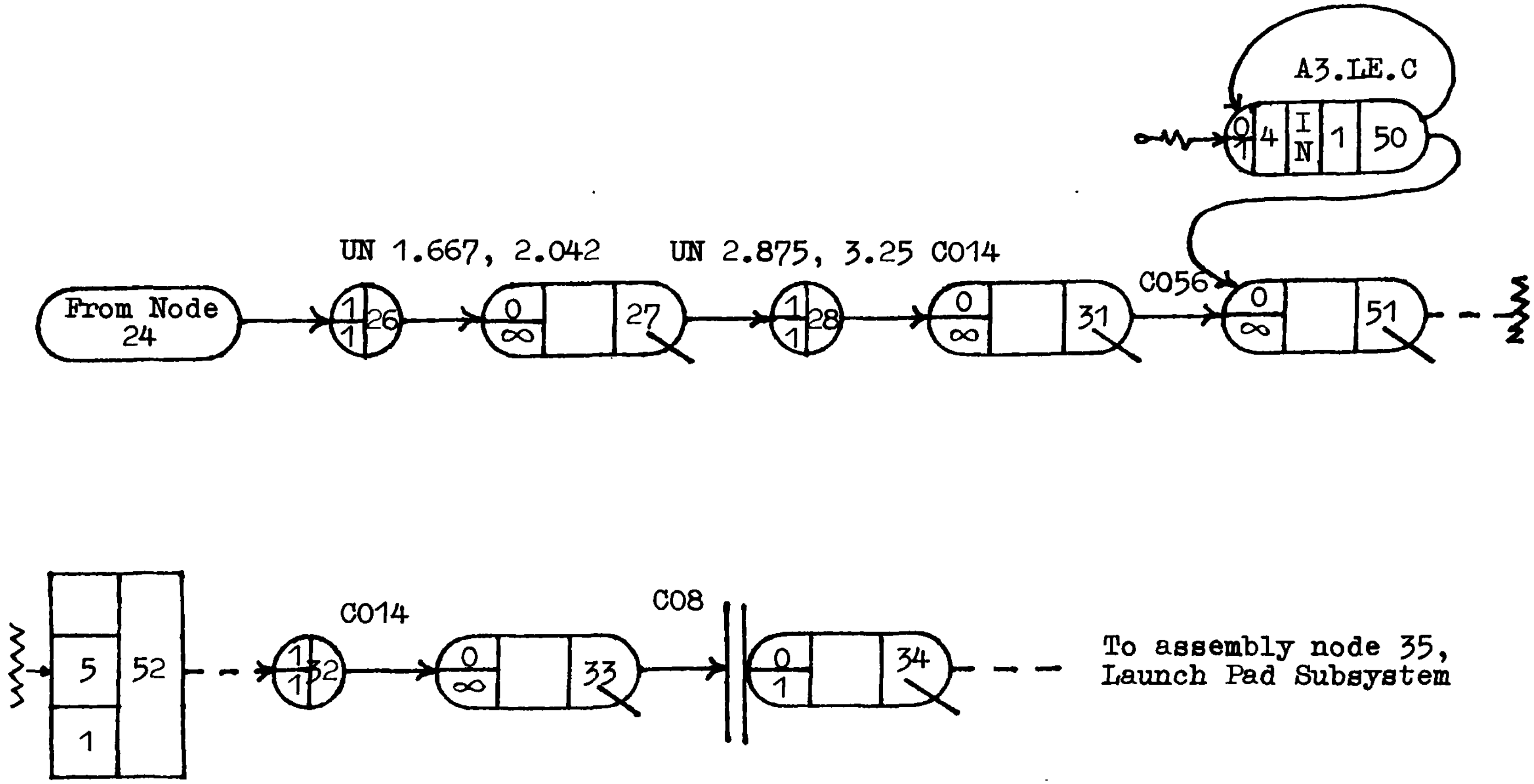


Figure 5

Solid Rocket Booster Subsystem Model

where they await shipment to VAFB. Allocate node 52 allocates one unit of resource 5, SRSF capacity. This technique assures that no more SRBs arrive at VAFB than can be stored in the SRSF. From node 52, each pair of SRBs is routed to regular node 32 which represents the shipment of SRB transactions from Ogden to VAFB.

The arrival of SRB transactions at queue node 33 represents the arrival of SRBs at the SRSF at VAFB. Functional SRBs that have been reassembled and/or checked out at the SRSF are routed to queue node 34 where they await stacking for launch at SLC-6.

Description of the Launch Pad Subsystem

The launch pad subsystem in Figure 6 integrates the transactions that have flowed through each of the other three subsystems. It represents the activities from SRB stacking, mating of the SRBs, ET, and Orbiter, vertical payload installation, and pad refurbishment after launch of the Space Shuttle.

The launch pad subsystem begins at allocate node 35 where one unit of resource 3, the launch pad, is allocated to an SRB transaction. If the launch pad is available, one transaction representing a set of operational SRBs is routed to queue node 36 which represents the beginning of SRB stacking at SLC-6. From node 36, transactions are routed to free node 53 which frees one unit of resource 5, SRSF

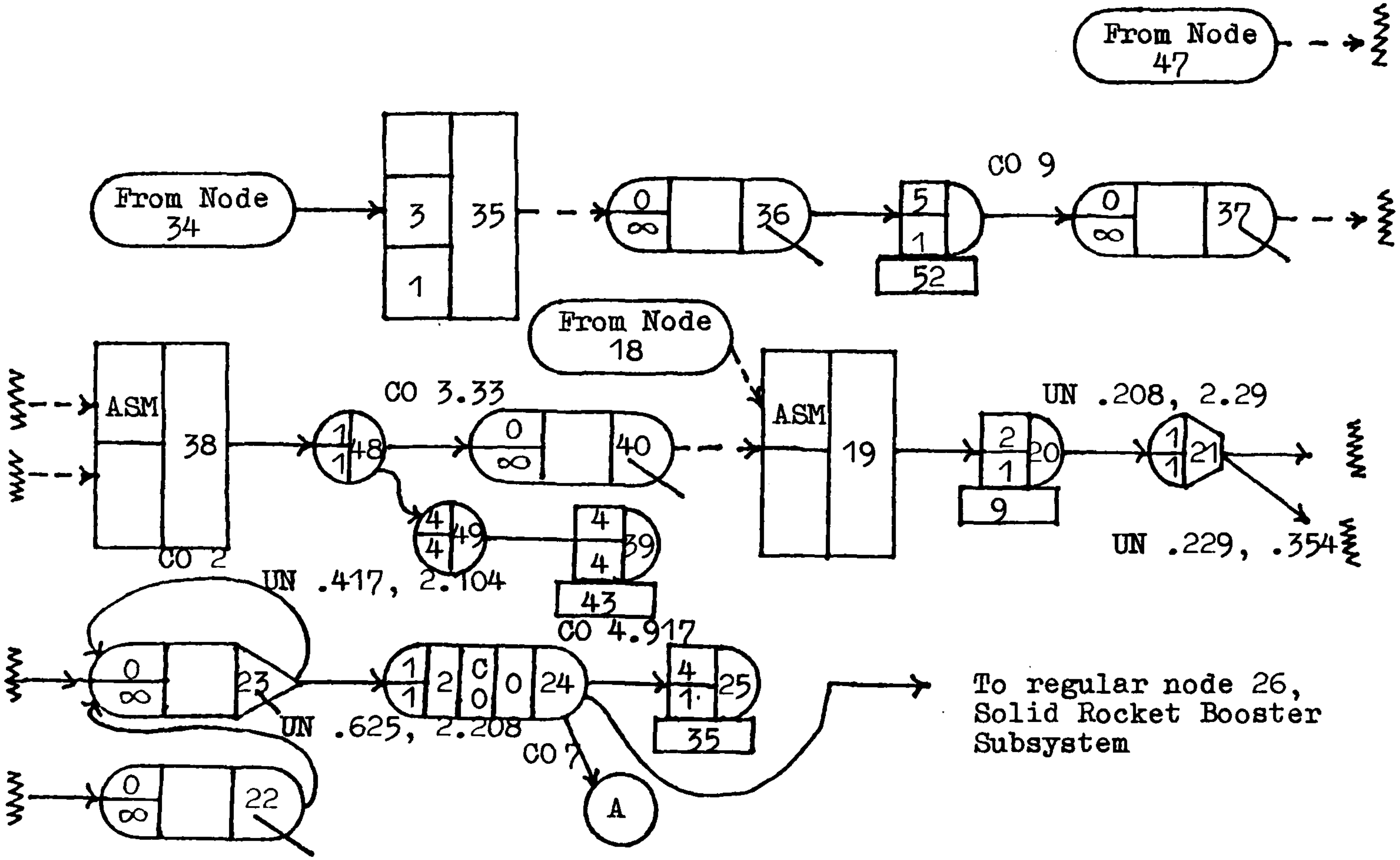


Figure 6

Launch Pad Subsystem Model

capacity, allowing a new or refurbished pair of SRBs to be shipped to VAFB. Upon completion of stacking operations, transactions are routed to queue node 37 where they await integration with an ET.

If an SRB transaction has arrived at node 37 and an ET transaction has arrived at node 47, integration of these two components can begin. This integration is represented by assembly node 38. The combined SRB/ET transactions are routed to regular node 48. Node 48 routes a transaction to regular node 49 which serves as an accumulator. When node 49 has accumulated four transactions (four integrations of an ET with stacked SRBs), it releases a transaction to free node 39. Node 39 will then free four units of resource 4, barge and TCF capacity, which in turn allows four more ETs to be loaded on a barge at the factor and be shipped to VAFB. The completion of the ET and SRB integration and checkout processes is represented by the arrival of an SRB/ET transaction at queue node 40 where the integrated ET and SRB await mating with the Orbiter.

If an SRB/ET transaction is located at node 40 and an Orbiter transaction is waiting at node 18, Orbiter integration may begin. Assembly node 19 represents the integration process.

The new Space Shuttle transaction is routed to free node 20 which allows the reallocation of OMCF capacity since one Orbiter has been removed from the OMCF and towed to

SLC-6. Node 20 also represents the Orbiter integration and checkout operations as a transaction is routed from node 20 to node 21.

Regular node 21 represents the completion of the integration process. Additionally, it checks the value of attribute 2, payload, through conditional take-first branching. If the value of attribute 2 is 1, the payload has already been installed while the Orbiter was in the OMCF and vertical payload operations are unnecessary. The transaction will be routed directly to node 23. If the value of attribute 2 is equal to 0, transactions are routed to queue node 22 which represents vertical payload operations. After vertical payload uploading, this Space Shuttle transaction is also routed to node 23.

Node 23 is a probabilistic queue node that represents to countdown process and the probability of delays related to weather. Assuming that weather delays occur ten percent of the time, when the weather delay branch is taken, countdown will be delayed. Once the countdown branch is taken, the countdown will begin and the Space Shuttle transaction is routed to statistics node 24.

Node 24 represents the launch of the Space Shuttle, the routing of an Orbiter transaction back into the Orbiter Maintenance Subsystem at node 2, and the routing of an SRB transaction to the Solid Rocket Booster Subsystem at node 26. Additionally, statistics node 24 collects interval statistics marked at node 2 of the Orbiter Maintenance Subsystem and sets attribute 2 to 0. From node 24, one additional transaction is routed to free node 25. This routing represents the start of the pad refurbishment process. The arrival of a transaction at node 25 will free one unit of resource 3, the launch pad, and initialize the Launch Pad Subsystem.

Research Design for Analysis of the Model

The network described in this chapter whose subsystems are depicted in Figures 3, 4, 5, and 6 was converted into the program displayed in Appendix B. This model provides the data that will be analyzed to determine the effect of different independent variables on the time required to complete a cycle of the VAFB Ground Turnaround System. In this research design, the independent variables are limited to the number of Orbiters available, ET production rate, and number of SRB sets available.

In analyzing these data, a search will be conducted for the optimal turnaround time resulting from various combinations of these three independent variables. By holding two of the independent variables constant while varying the values of the third, an optimal turnaround can be derived.

Analysis of variance testing will be used to interpret the results of the simulations because its objective is to locate the important independent variables in the research design and determine how they affect the dependent variable. Each simulation run, consisting of ten iterations, will provide the mean time required to launch a Space Shuttle mission given the specified values of the independent variable. An analysis of variance will test the variance between the sample means. If the sample means are found to be equal, then varying the quantities of available Space Shuttle components will not affect the time between recovery of an Orbiter and launch of a Space Shuttle.

To determine the sensitivity of the model to change, the ET generation capacity will be varied between 8 and 20 units while the number of available SRB pairs will vary between 6 and 11. Additionally, the number of Orbiters available for launch at Vandenberg will vary from 1 to 4. A sample table is presented in Figure 7 to illustrate the various combinations of component availability.

Available Orbiters

SRB Sets Available	Production Rate of Orbiters			
	8	12	16	20
6				
7				
8				
9				
10				
11				

Figure 7

Sample Table of Mean Ground Turnaround Times

Model Verification

Having tanslated the model into a computer program, simulation runs were conducted for verification of the model to ensure the model would act in the way the designers intended.

The first simulation run was done on the initial portion of the networks to ensure that the proper number of transactions representing Orbiters and ETs were being generated from source nodes 1 and 41. A second test run was made of a source node releasing transactions to a regular node with conditional take-first branching which releases transactions to a common queue node. This verified the model's ability to simulate deservicing of a returned Orbiter and forwarding it to the OMCF. A third simulation was required to test the flow of transactions through allocation nodes 4, 9, 43, 35, and 52 to free nodes 10 and 11, 20, 39, 25, and 53. This test verified that space in the SDF and OMCF could be allocated to an Orbiter and released when the Orbiter had passed through that activity. Additionally, space could be reserved on a barge for shipment of ETs to Vandenberg when space was available in the TCF, and the launch pad could be allocated to launch a Space Shuttle and be made free for another mission as soon as pad refurbishment was complete.

The final internal verification simulation run of a simplified network tested the flow of transactions through assembly nodes 38 and 19 into regular nodes. This final test verified the integration of shuttle components and their continued flow as a combined transaction through the network representing the VAFB Ground Turnaround System.

This chapter discussed the assumptions necessary to turn a complex system into a network model, the details of the working Q-GERT model, and the research design for analyzing the sensitivity of change in independent variables. Chapter 4 will discuss the results of the simulation runs and the analysis of the statistics compiled on these runs.

Chapter 4

RESULTS AND ANALYSIS

As discussed in Chapter 3, the model was run several times in search of a steady state point where the variance of results of different runs was minimal. Analysis of the search indicates that this model, due to system design, is initialed in a steady state thereby allowing the collection of data from event time 0.0 through 400.0 simulated days.

By varying the number of available Orbiters, the number of available SRB sets, and the production rate of ETs, 96 different simulations consisting of 10 runs each were conducted. The results of these simulations are provided in Tables 1 through 4 which reflect the mean ground turnaround times, in days , for a given combination of independent variables. A three-way analysis of variance was performed on the simulation results to determine the significant effects, if any, of the independent variables on the dependent variable, as well as the interactions of the independent variables.

This research will not discuss the concept of the analysis of variance process or its development. For those interested in an indepth description of analysis of variance (ANOVA), the authors recommend the following sources for their excellent explanations:

<u>Statistical Package for the Social Science: SPSS</u> (13)

<u>The Analysis of Variance</u> (15)

<u>Statistics For Business and Economics</u> (11).

Turnaround Results

The mean ground turnaround times resulting from various combinations of Space Shuttle components are shown in Tables 1 through 4. These mean times were tested to determine whether they differed significantly. Because there were three independent variables, a three-way analysis of variance test was performed using the following null hypothesis and alternate hypothesis:

H_o: all test means are equal

H_a: all test means are not equal.

In testing the null hypothesis, a comparison of within-treatment variance and between-treatment variance is required. Because this research includes three main effect treatments (the independent variables) and four interaction treatments, seven comparisons of variance must be made (15: 119-121). Utilizing the ANOVA technique (13:398-433), the variance due to the number of Orbiters (A), the number of ETs (B), the number of SRB sets (C), the interaction between Orbiters and ETs (AB), the interaction between Orbiters and SRBs (AC), the interaction between ETs and SRBs (BC), and the interaction between Orbiters, SRBs, and ETs (ABC) is tested.

Table 1

Mean Ground Turnaround Times
1 Available Orbiter

SRB Sets Available	Production Rate of ETs			
	8	12	16	20
6	75.4	88.7	95.6	95.6
7	76.4	92.9	98.8	100.2
8	76.9	86.2	87.7	95.1
9	76.9	87.1	92.2	98.1
10	76.9	88.1	90.2	92.9
11	76.9	90.5	73.2	95.7

Table 2

Mean Ground Turnaround Times
2 Available Orbiters

SRB Sets Available	Production Rate of ETs			
	8	12	16	20
6	85.9	107.5	111.2	111.1
7	86.9	99.4	102.2	101.2
8	86.9	96.9	95.6	101.2
9	86.9	97.2	108.5	105.4
10	86.9	98.8	96.3	105.9
11	86.9	99.8	103.4	124.8

Table 3

Mean Ground Turnaround Times
3 Available Orbiters

SRB Sets Available	Production Rate of ETs			
	8	12	16	20
6	107.3	119.5	116.9	116.1
7	107.3	110.8	108.3	113.0
8	107.3	115.9	113.4	121.1
9	107.3	117.5	117.3	122.1
10	107.3	118.9	101.9	122.8
11	107.3	118.9	111.6	116.7

Table 4

Mean Ground Turnaround Times
4 Available Orbiters

SRB Sets Available	Production Rate of ETs			
	8	12	16	20
6	123.3	131.9	139.4	141.3
7	123.3	125.8	133.5	125.9
8	123.3	124.9	135.2	129.9
9	123.3	124.2	122.4	131.3
10	123.3	124.2	117.7	131.2
11	123.3	124.2	129.9	145.2

In testing the main effects and interaction relationships, a 95 percent level of confidence was established. The test statistic used in this model is:

$$F = \frac{MST}{MSE}$$

where MST is the mean square of the treatment and MSE is the mean square error. The decision rule for the test statistic is as follows:

if $F^* \leq F[.95(df), 60]$ fail to reject H_o

if $F^* > F[.95(df), 60]$ reject H_o

If the hypothesis for the global F ratio is rejected, then the treatment means (the mean ground turnaround times) are not equal and further investigation of the individual treatment variances is possible. In other words, if H_o is rejected, then the mean ground turnaround time is affected by at least one of the independent variables. The hypothesis tested for the treatment mean is as follows:

T_1: variance associated with treatment = 0

T_A: variance associated with treatment $\neq$ 0

If T_A is accepted, that is, the variance of the treatments is not zero, then the treatment has a significant effect on the variable of interest.

The results of the SPSS ANOVA accomplished on the Harris computer at the Air Force Institute of Technology are summarized in Table 5.

Table 5

Three-Way Analysis of Variance--VAFB Ground Turnaround Times

Variables	Sum of Squares	Mean Squares	Degree of Freedom (df)	$\frac{MST}{MSE} = F^*$	$F, \alpha .05$
Main Effects	22965.677	3280.811	7	52.394	2.17
A	19649.359	9824.680	2	156.897	3.15
B	3090.108	1545.054	2	24.674	3.15
C	226.211	75.404	3	1.204	2.76
Two-Way Interactions	851.904	53.244	16	.850	1.84
A With B	180.876	45.219	4	.722	2.53
A With C	300.299	50.050	6	.799	2.25
B With C	370.729	61.788	6	.987	2.25
Three-Way Interactions	176.557	14.713	12	.235	1.92
A With B With C	176.557	14.713	12	.235	1.92
Error	3757.114	62.619	60		
Total	27751.252	292.118	95		

With the model limited by the assumptions discussed in Chapter 3, the results of the analysis of variance testing indicate that only the main effects of the number of orbiters (A) and the production rate of ETs (B) cause a rejection of the test hypothesis. The number of SRB sets (C) and all of the interaction terms fail to reject the hypothesis. Because of these results, further investigation of the ET, Orbiter Maintenance, and Launch Pad Subsystems is required. The statistics for this investigation are provided in the Q-GERT statistical summary.

Sensitivity of the ET Subsystem

Analysis of the ET subsystem statistics from the Q-GERT statistics analysis depicted in Tables 6 - 9 indicates that at low ET production rates, the mean waiting time for launch pads is longer. This effect is not readily apparent in Tables 1 - 3 because the research design only provides for data collection at launch of a Space Shuttle. Therefore, if a prepared Space Shuttle waits within the VAFB Ground Turnaround System at the end of a computer run of 400 simulated days, the statistics accumulated by that particular Orbiter, set of SRBs, and ET would not be included, regardless of length of time spent in maintenance or in a queue, because it had not been launched.

Consequently, the absence of available ETs to integrate with SRBs on the launch pad contributes significantly to an increase in the Ground Turnaround Time. However, this effect only occurs when the production rate of ETs falls below 16 per 400 simulated days. When the assumed production rate of ETs is 16 or higher per 400 simulated days, the production rate does not contribute significantly to the ground turnaround time. The analysis of variance and the Q-GERT statistical reports indicate that the ground turnaround time is more sensitive to the number of Orbiters in the system than to the production rate of ETs. Therefore, since Orbiters only appear in the Orbiter Maintenance and Launch Pad Subsystems, additional study of these subsystems is required to determine if they are the cause of this significant effect on the VAFB Ground Turnaround System.

Sensitivity of the Orbiter Maintenance and Launch Pad Subsystems

The Average Waiting Time in Queue statistic on the Q-GERT statistical summary is used to provide an indication of bottlenecks. In the Orbiter Maintenance and Launch Pad Subsystems, the only significant waiting time occurs at queue node 18 where a prepared Orbiter awaits an available launch pad. Although some waiting time can be anticipated in the real system, the Summary of Waiting Time results in Tables 6 through 9 indicate waiting times the authors believe to be excessive, even for a single Orbiter. These excessive mean waiting times are a primary indicator that launch pad

Table 6

Mean Waiting Time For Launch Pad
1 Available Orbiter

SRB Sets Available	Production Rate of ETs			
	8	12	16	20
6	25.8	19.2	19.0	19.0
7	25.8	16.4	16.4	16.4
8	25.8	14.1	14.2	14.1
9	25.8	14.1	12.4	12.4
10	25.8	14.1	10.5	10.5
11	25.8	14.1	9.1	9.0

Table 7

Mean Waiting Time For Launch Pad
2 Available Orbiters

SRB Sets Available	Production Rate of ETs			
	8	12	16	20
6	59.5	48.1	48.0	48.1
7	59.5	43.3	43.5	43.5
8	59.5	39.7	39.7	43.5
9	59.5	39.7	35.9	36.2
10	59.5	39.7	32.9	33.0
11	59.5	39.7	30.5	30.2

Table 8

Mean Waiting Time For Launch Pad
3 Available Orbiters

SRB Sets Available	Production Rate of ETs			
	8	12	16	20
6	68.8	57.5	57.4	57.4
7	68.8	53.1	53.2	53.1
8	68.8	49.3	49.3	49.3
9	68.8	49.4	45.8	46.1
10	68.8	49.3	43.1	43.1
11	68.8	49.3	40.4	40.4

Table 9

Mean Waiting Time For Launch Pad
4 Available Orbiters

SRB Sets Available	Production Rate of ETs			
	8	12	16	20
6	68.7	57.6	57.6	57.6
7	68.7	53.2	53.3	53.2
8	68.7	49.4	49.4	49.3
9	68.7	49.4	46.1	46.0
10	68.7	49.4	43.3	43.2
11	68.7	49.4	40.5	40.6

availability creates a bottleneck in the VAFB Ground Turnaround System.

To further investigate the sensitivity of the Launch Pad Subsystem, an additional analysis of variance on ground turnaround time was accomplished using a 10, 20, 30, and 40 percent reduction in all times used to perform operations in the Launch Pad Subsystem, i.e., mating the Orbiter with the ET and SRBs, countdown procedures, etc. The results of this analysis, shown in Table 10, were tested to determine if the test means differed significantly. The null hypothesis and alternate hypothesis being tested for this one-way analysis of variance (one independent variable) are as follows:

H_o: all test means are equal

H_a: all test means are not equal.

Table 10

Mean Ground Turnaround Time*

Reduction in Pad Parameters	Number of Orbiters			
	1	2	3	4
0%	95.7	124.8	116.7	145.2
10%	87.6	118.3	113.0	132.2
20%	65.2	96.9	93.9	113.7
30%	50.3	86.8	92.9	99.4
40%	35.4	81.5	87.5	96.2

*For a fixed ET production rate of 20 sets/yr. and 11 SRB sets available.

As before, using the SPSS ANOVA, the variance due to the percentage reduction of launch pad maintenance times (D) was tested. The results of this analysis of variance testing are shown in Table 11. As seen, these results indicate that the null hypothesis should be rejected because all test means are not equal. Therefore, the reduction of launch pad maintenance times will have a significant effect on the ground turnaround time.

Table 11

One-Way Analysis of Variance--
Reduction In Pad Parameters

Variable	Sum of Squares	Mean Squares	DF	$\frac{MST}{MSE}$	F, α .05
Main Effects	6072.833	1518.208	4	3.171	3.06
D	6072.833	1518.208	4	3.171	3.06
Error	7180.755	478.717	15		
Total	13253.588	697.557	19		

Summary of Results

The results of this analysis of the VAFB Ground Turnaround System indicate that both the ET Subsystem and Launch Pad Subsystem have significant impact on the mean ground turnaround time. Further analysis indicated that the Launch Pad Subsystem is most sensitive to change. Additionally, this analysis indicates that the ground turnaround times are affected by the number of Orbiters available in the system.

This observation is intuitively obvious because the limited launch pad resource forces mission-ready Orbiters to remain in queue in the OMCF until the launch pad is available.

This chapter has discussed the results and analysis of simulations performed using the Q-GERT model of the VAFB Ground Turnaround System. The following, and final, chapter will discuss the answers to the research questions posed in Chapter 1, discuss the limitations of the assumptions made by the authors in designing the model, and provide recommendations for further study and research.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

The first chapter of this thesis introduced the research objective which would be met by answering three research questions.

1. What is the structure of the Space Shuttle Ground Turnaround System at VAFB?

2. What are the interactions among the major subsystems of the VAFB Ground Turnaround System?

3. Which of these subsystems are most sensitive to change?

The following sections will discuss the answers to the research questions, discuss the limitations of the assumptions made in designing the model, and discuss further studies recommended by the authors.

Conclusions of the Research Questions

The first research question regarding the structure of the VAFB Ground Turnaround System was answered in Chapter 2. In fully describing the system, four major subsystems were identified. Research question two asked about the interactions between the major subsystems; this question was also answered in Chapter 2 with a thorough discussion of the operations and transfers of transactions between and among the subsystems.

The final research question asked which of the subsystems were more sensitive to change. In Chapter 4, the independent variables (Orbiters, SRBs, and ETs) were varied to provide a given ground turnaround time (dependent variable) for a given combination of independent variables. An analysis of variance conducted on the dependent variable and analysis of Q-GERT data as discussed in Chapter 4 indicate that the Launch Pad Subsystem of the VAFB Ground Turnaround System is most sensitive to change. However, in designing the model to develop a ground turnaround time, assumptions had to be made to transform a complex system into a model.

<u>Conclusions About the Affects of Assumptions</u>

One of the assumptions in the Orbiter Maintenance Subsystem was that no logistical support problems existed. All Orbiter maintenance was accomplished in an environment where appropriations were unlimited and spares were always available. While unrealistic, this assumption allowed the modelers to gloss over a weakness in the current data base; not enough data about shuttle maintenance are available to determine what parts will require spares, and how many spares should be maintained in inventory. Obviously, appropriation limitations will restrict the quantity of available spares.

Because of this assumption, further study of spares reliability, availability, and their impact on the OMCF as a separate system is recommended. By analyzing the impact of spares limitations on the maintenance process, a better estimation could be made about the maintenance time required in the VAFB Ground Turnaround System.

In the SRB subsystem, two of the assumptions requiring further discussion concern storage capacity in the SRSF and transportation of SRBs. In designing the model, a perfect transportation environment was envisioned between Port Hueneme, Thiokol, and VAFB. Schedules were met, storage was available, and railcars were prepositioned. Since no data are yet available, this assumption is unavoidable. Further study is recommended as soon as feasible on the actual transportation network to determine the effects of delays in shipment on the refurbishment process and the Ground Turnaround System.

Capacity in the SRSF is two sets of SRBs. In discussion with officials at Vandenberg's Space Shuttle Logistics Division (6), it was determined that while the SRSF could hold more SRBs, current safety regulations prohibit more than two SRB sets from being stored in the SRSF. Other SRBs will be stored at Thiokol and KSC (which is allowed to store a larger number of SRBs), and shipped to VAFB as needed. Further study is needed on the amount of storage capacity that will be available at the SRSF or alternate storage sites at Vandenberg. This study would be enhanced with a cost/benefit analysis of changing SRB storage procedures/facilities to comply with safety regulations so that multiple sets of SRBs can be stored at VAFB versus storing only two SRBs at VAFB and shipping in other sets on an as-required basis. In the latter situation, the previous recommendation to study the transportation network is substantiated.

Conclusions About the Results of This Thesis

This model was designed around the research questions rather than to exactly duplicate the system as planned at Vandenberg. Consequently, only the major components of the system were examined in detail. Regardless, this model of the VAFB Ground Turnaround System can be used by planners to predict turnaround times for Space Shuttles landing and launching from Vandenberg and to anticipate bottlenecks in the Ground Turnaround System.

The design concepts of the model are applicable to the real system, as it is currently designed. As more data about maintenance time, transportation time, and production rates become available, the validity of this model will increase.

Recommendations

Having studied the results of this thesis, the authors strongly recommend further study and expansion of this model. Discussion with planners at VAFB indicates that changes in design and procedures at the proposed VAFB

Ground Turnaround System occur continually (6). By modifying this model as changes are proposed, planners can use the model as a tool to predict the ground turnaround time given a specific change.

As more data become available, launch managers can use the model to estimate the number of components, number of ground crews, and number of manhours necessary to maintain a given launch rate. For example, under the assumptions of this model, launch pad availability creates a bottleneck that limits Orbiter turnaround and thus reduces a sustained launch rate. Given this limiting factor, management must determine what launch pad maintenance time will support the desired launch rate and then take action to modify the current pad maintenance environment accordingly.

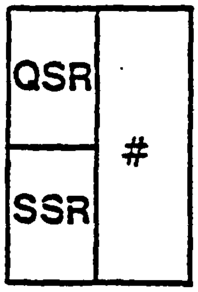
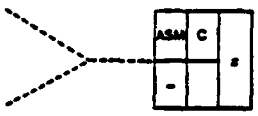
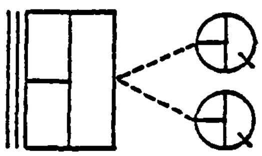
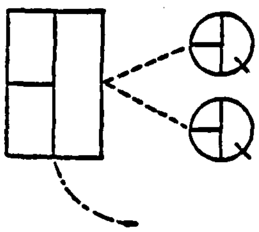
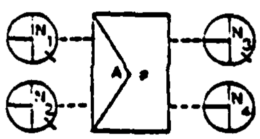
In view of the limitations imposed by the launch pad, the authors recommend this area for further study. At a minimum, research in the launch pad area should emphasize methods to reduce maintenance times necessary to support operations in the Launch Pad Subsystem. For example, a faster integration of shuttle components will improve the Space Shuttle launch rate.

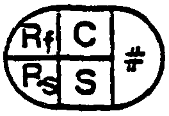
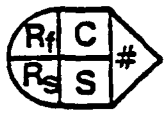
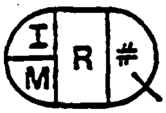
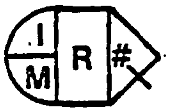
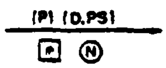
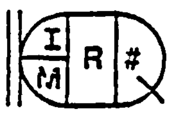
Summary

In spite of the complexity of the VAFB Ground Turnaround System, it has been simulated with a network model that has been verified. While the results of simulation are restricted by assumptions that are currently necessary, the model still provides an instrument for planners to predict ground turnaround times. With adjustments to the model, supported by results of recommended studies, planners can improve their ability to predict bottlenecks, anticipate problems, and support a desired Space Shuttle launch rate from Vandenberg.

APPENDIX A

Q-GERT SYMBOLS

Symbol	Concept	Definition
	Selector node or S-node	QSR is the queue selection rule for routing transactions to or from Q-nodes (see Table 5-2). SSR is the server selection rule for deciding which server to make busy if a choice exists (see Table 5-3). # is the S-node number.
	Routing Indicator	Routing indicator for transaction flow to or from Q-nodes to S-nodes or Match nodes
	Assembly by S-nodes	ASM is the queue selection rule that requires transactions to be assembled from two or more queues.
	Blocking	Blocking at an S-node.
	Balking	Balking from an S-node.
	Match Node	# is the match node number. Transactions are routed from N_1 to N_3 and N_2 to N_4 when a match occurs. A is the attribute number on which the match is to be made

Symbol	Definition
 	R_f is the number of incoming transactions required to release the node for the first time. R_s is the number of incoming transactions required to release the node for all subsequent times. C is the criterion for holding the attribute set at a node. S is the statistics collection type or marking. # is the node number.  indicates deterministic branching from the node.  indicates probabilistic branching from the node.
 	I is the initial number of transactions at the Q-node. M is the maximum number of transactions permitted at the Q-node. R is the ranking procedure for ordering transactions at the Q-node. # is the Q-node number.
	Pointer to a source node or from a sink node.
	P is the probability of taking the activity (only used if probabilistic branching from the start node of the activity is specified). D is the distribution or function type from which the activity time is to be determined. PS is the parameter set number (or constant value) where the parameters for the activity time are specified. $\boxed{\#}$ is the activity number N is the number of parallel servers associated with the activity (only used if the start node of the activity is a Q-node).
	Routing of a transaction that balks from a Q-node. This symbol can not emanate from a regular node.
	Blocking indicator (only used with Q-nodes that can force preceding *service* activities to hold transactions because the Q-node is at its maximum capacity).

APPENDIX B

VAFB GROUND TURNAROUND SYSTEM NETWORK MODEL

```
100=TWJ,CY177000,T60. T920430,JONES.
110=ATTACH,PROCFIL,QGERTPROC,ID=AFIT.
120=BEGIN,QGERT,PROCFIL.
130=*EOR
140=GEN,STERRY,STS,6,10,82,1,0,,400,10,F,0,3*
150=SOU,1,0,1,A,F*
160=VAS,1,1,IN,1*
170=REG,2,1,1,D,M*
180=QUE,3/LANDING,(10)4*
190=ALL,4,POR,1,1,3/5*
200=RES,1/SDFSERV,1,4*
210=QUE,5/SDF*
220=REG,6,1,1,P*
230=QUE,7,(10)9*
240=QUE,8,(10)9*
250=ALL,9,POR,2,1,7/10,8/11*
260=RES,2/OMCFSERV,2,9*
270=FRE,10,D,1,1,4*
280=FRE,11,D,1,1,4*
290=QUE,12/PLDOWN*
300=QUE,15/SCHDMX*
310=REG,16,1,1,P*
320=QUE,17/LOADPL*
330=VAS,17,2,CO,1*
340=QUE,18/READYOB,(10)19*
350=SEL,19/STACKOB,ASM,,8/2,,18,40*
360=FRE,20,D,2,1,9*
370=REG,21,1,1,F*
380=QUE,22/LOADPL*
390=QUE,23/COUNTDN,0,1,P*
400=STA,24/LAUNCH,1,1,D,I*
410=VAS,24,2,CO,0*
420=FRE,25,D,3,1,35*
430=REG,26,1,1*
440=QUE,27/SRBDIS*
450=REG,28,1,1*
460=QUE,31/SRBRFB*
470=SOU,50,0,1,A,F*
480=VAS,50,3,IN,1*
490=QUE,51/SRBWAIT,(10)52*
500=ALL,52,POR,5,1,51/32*
510=RES,5/SRBCAP,2,52*
520=REG,32,1,1*
530=QUE,33/SRSF*
540=QUE,34,0,1,D,F,B,(10)35*
550=ALL,35,POR,3,1,34/36*
560=RES,3/PAD,1,35*
570=QUE,36/SRBSTK*
580=FRE,53,D,5,1,52*
590=QUE,37,(10)39*
```

```
600=SEL,38/ETSTK,ASM,,B/2,,37,47*
610=FRE,39,D,4,4,43*
620=QUE,40,(10)19*
630=SOU,41,0,1*
640=QUE,42/ET,(10)43*
650=ALL,43,POR,4,1,42/44*
660=RES,4/ETCAP,4,43*
670=REG,44,1,1*
680=REG,45,1,1*
690=QUE,46/ETCF*
700=QUE,47,1,5,D,F,,(10)38*
710=REG,48,1,1*
720=REG,49,4,4*
730=ACT,1,1,CO,0,1,(9)A1.LT.(A)*
740=ACT,1,2*
750=ACT,2,3,CO,.042,2*
760=ACT,5,6,UN,1,3*
770=ACT,6,7,CO,0,4,(8).2*
780=ACT,6,8,CO,0,5,(8).8*
790=ACT,10,12*
800=ACT,11,15*
810=ACT,12,15,UN,2,6,2*
820=ACT,15,16,UN,3,7,2*
830=ACT,16,17,CO,0,8,(8).5*
840=ACT,16,18,CO,0,9,(8).5*
850=ACT,17,16,CO,0,10,2*
860=ACT,19,20*
870=ACT,20,21,UN,4,11*
880=ACT,21,23,UN,5,12,(9)A2.EQ.1*
890=ACT,21,22*
900=ACT,22,23,UN,6,13*
910=ACT,23,23,CO,2,14,(8).1*
920=ACT,23,24,UN,7,14,(8).9*
930=ACT,24,2,CO,7,15*
940=ACT,24,25,CO,4.917,16*
950=ACT,24,26*
960=ACT,26,27,UN,8,17*
970=ACT,27,28,UN,9,18*
980=ACT,28,31,CO,14,19*
990=ACT,31,51,CO,56,20*
1000=ACT,50,50,CO,0,29,(9)A3.LE.(C)*
1010=ACT,50,51*
1020=ACT,32,33,CO,14,21*
1030=ACT,33,34,CO,8,22*
1040=ACT,36,53*
1050=ACT,53,37,CO,9.167,23*
1060=ACT,38,48*
1070=ACT,48,40,CO,3.33,24*
1080=ACT,48,49*
1090=ACT,49,39*
```

```
100=ACT,41,41,CO,(B),25*
1110=ACT,41,42*
1120=ACT,41,42*
1130=ACT,41,42*
1140=ACT,41,42*
1150=ACT,44,45,UN,10,26*
1160=ACT,45,46,CO,.833,27*
1170=ACT,46,47,CO,8.883,28*
1180=PAR,1,,.417,1.08*
1190=PAR,2,,.229,.563*
1200=PAR,3,,1.979,5.563*
1210=PAR,4,,.208,2.29*
1220=PAR,5,,.229,.354*
1230=PAR,6,,.625,2.208*
1240=PAR,7,,.417,2.104*
1250=PAR,8,,1.667,2.042*
1260=PAR,9,,2.875,3.25*
1270=PAR,10,,14.,21.*
1280=FIN*
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SELECTED BIBLIOGRAPHY

A. REFERENCES CITED

1. Borrowman, Gerald L. "Space Shuttle at Vandenberg," Space Flight, Vol. 23, No. 4 (April 1981), pp. 96-101.

2. Covault, Craig. "New Space Policy Directives Expected," Aviation Week and Space Technology, (March 8, 1982), pp. 79-80.

3. ________. "Problems in Shuttle Launch Operations at Vandenberg," Aviation Week and Space Technology, (August 24, 1981), pp. 22-23.

4. ________. "Shuttle Management Shifting to Operations," Aviation Week and Space Technology, (December 21, 1981), pp. 12-15.

5. ________. "Space Shuttle Flight Assignment Schedule Developed," Aviation Week and Space Technology, (March 8, 1982), pp. 100-101.

6. Cox, John. Logistic Analysis, SD/LT, Vandenberg AFB CA. Telephone interview. 21 May 1982.

7. Famigliette, Leonard. "5000 to Work at Space Port," Air Force Times, Vol. 42, No. 32 (March 1, 1982), p. 28.

8. Gatland, Kenneth W. "Space Shuttle," Spaceflight, Vol. 23, No. 3 (March 1981), p. 64.

9. Grey, Jerry. "Case for a Fifth Shuttle and More Expendable Launch Vehicles," Astronautics and Aeronautics, (March 1981), pp. 22-25.

10. Martin Marietta. DOD STS Ground Support Systems Integration. Martin Document VCR-81-252, Denver CO, 29 September 1981.

11. McClave, James T. and P. George Benson. Statistics for Business and Economics. San Francisco: Dellen Publishing Company, 1979.

12. National Aeronautics and Space Administration. Shuttle Turnaround Analysis Report. John F. Kennedy Space Center, May 28, 1981.

13. Nie, Norman H., and others. Statistical Package for the Social Sciences: SPSS. 2d ed. New York: McGraw-Hill Book Company, 1975.

14. Pritsker, A. Alan B. Modeling and Analysis Using Q-GERT Networks. New York: John Wiley & Sons, 1979.

15. Scheffe, Henry. The Analysis of Variance. New York: John Wiley & Sons, 1959.

16. Scott, Harry A. "Space Shuttle," Astronautics and Aeronautics, (June 1979), pp. 54-59.

17. Shannon, Robert E. Systems Simulation: The Act and Science. Englewood Cliffs NJ: Prentice-Hall, Inc., 1975.

18. Sheppard Technical Training Center, Air Training Command. Space Shuttle Vehicle STS Familiarization Course (V-23), HOJ40 SF 2895-001-001. Sheppard AFB TX, August 1981.

19. Sloan, Lt. Col. Aubrey B., USAF. "Vandenberg Planning for the Space Transportation Systems," Astronautics and Aeronautics, (November 1981), pp. 44-50.

20. Smith, Bruce A. "Vandenberg Readied for Shuttle Launch," Aviation Week and Space Technology, (December 7, 1981), pp. 49-52.

21. Space Division, Air Force Systems Command. DOD STS Ground Support System Integrated Logistics Support Plan. SD-YV-0070. Los Angeles AFS CA, 1 January 1982.

B. RELATED SOURCES

Barr, David R., Assistant Professor of Mathmatics, AFIT/ENG, Wright-Patterson AFB OH. Lectures from 5 October 1981 through 17 December 1981.

Byler, Major Rodney C., USAF. Instructor in Logistics Management, AFIT/LSM, Wright-Patterson AFB OH. Personal interviews conducted intermittently from 5 October 1981 to 30 June 1982.

Clark, Lieutenant Colonel Thomas D., Jr., USAF, Assistant Professor of Operations Research and Applied Sciences, AFIT/ENG, Wright-Patterson AFB OH. Lectures from 5 October 1981 through 17 December 1981.

Gullett, Captain Harry W., USAF, and Captain Thomas N. Stiver, USAF. "A Study and Model of the Noncombatant Evacuation Operation in the Federal Republic of Germany." Unpublished master's thesis. LSSR 8-80. AFIT/LSH, Wright-Patterson AFB OH, June 1980. AD A090734.

Martin, Captain David, USAF. Chief, Logistics Space Analysis Division, Kirkland AFB NM. Telephone interview. 20 April 1982.

Masters, Major James M., USAF, Assistant Professor of Operations Research, AFIT/LSB, Wright-Patterson AFB OH. Personal interviews conducted intermittently from 16 March 1982 to 2 June 1982.