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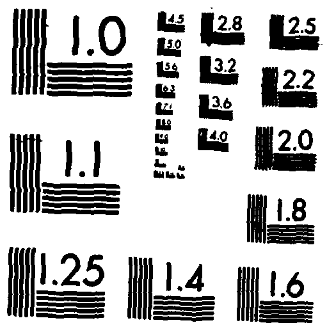
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AF INSTITUTE OF TECHNOLOGY

A Q-GERT NETWORK SIMULATION MODEL FOR EXAMINING PIPELINE TIME IN THE NAVY'S J-52 INTERMEDIATE LEVEL JET ENGINE REPAIR CYCLE

THESIS

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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
Requirements for the Degree of
Master of Science in Logistics Management

Michael N. Romero, B.S.
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Preface

The goal of this project was to develop a computer simulation model of the repair pipeline for the U.S. Navy's J-52 jet engine. Hopefully, I have conveyed the point that the model answers no single question, but that it can be used as a management tool to investigate several questions or problem areas dealing with the inefficient use of resources.

In putting this model together, I relied on existing maintenance directives, interviews, and personal experience. To demonstrate the model's application, I established a hypothetical scenario with contrived parameters in order to convert the model to code and run it on the computer. Results of the output are explained in order to give the reader some idea as to the model's use.

A great deal of thanks is in order for my thesis advisor, Mr. Jim Meadows, for his patience and expert guidance. I would also like to thank LCDR John VanSickle at NAVAIRSYSCOM for his "in the field" advice, and also Dr. Charles Fenno, whose scholarly advice helped steer me away from making this report sound like it was written by a government employee.

Words cannot express my sincere appreciation for my lovely wife, Nancy, and her countless hours of typing on this report. She and the children, Mike, Larry, and Angela, sacrificed more than what should be expected as this thesis was going through its growing pains.

Finally, I humbly express my deepest thanks to the Lord who carried me so securely over the countless hurdles that only He and I are aware of. I cannot imagine ever tackling a project of this magnitude without Him.

Michael N. Romero

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Abstract

Repairs on jet engines of Naval aircraft are performed in accordance with the three-level concept prescribed by the Naval Aviation Maintenance Program (NAMP) - organizational, intermediate, and depot level. At the intermediate level, the entire repair cycle is referred to as the pipeline and includes time expended in transit, storage, administrative processing, actual repair, awaiting maintenance (AWM) time, and awaiting parts (AWP) time. Existing repair system directives specify a standard turnaround time (TAT) for engines in the repair cycle pipeline. Recent data, however, indicates that the actual TAT for the J-52 engine is almost four times the standard specified by the directives. One approach to investigating this excessive time in the pipeline is to examine the operation of the repair system, focussing attention on the utilization of resources. The objective of this project, therefore, was to develop a computer simulation model which replicates the J-52 intermediate level repair cycle, concentrating on repair crews, workstands, and test cells as the major resources employed. The intended use of the model is as a management tool in which backlogs and delays at various points in the pipeline can be identified, thereby allowing managers to adjust or reallocate resources as required to achieve a more efficient operation and, hence, a lower TAT. A hypothetical scenario based on contrived parameters was developed in order to convert the model to code and demonstrate its application on the computer. The results of a sample simulation run show that excessive repair backlogs and delays as well as inefficient resource utilization can, in fact, be identified in the output, thereby

paving the way for management to experiment with different resource utilization schemes in order to achieve a lower TAT.

A Q-GERT NETWORK SIMULATION MODEL FOR EXAMINING PIPELINE TIME IN THE NAVY'S J-52 INTERMEDIATE LEVEL JET ENGINE REPAIR CYCLE

I. Introduction

Chapter Overview

This research project takes an investigative look at a key management issue within the Navy's J-52 repair system using simulation modeling as the primary tool. This first chapter provides background information related to the J-52 repair system, followed by a statement of the problem, the research objectives, the investigative questions, the scope and limitations of the project, the assumptions made, and, finally, the justification for the research.

Background

The Pratt and Whitney J-52 turbojet engine is one of the most widely used engines in Naval Aviation. Three models of the J-52 engine comprise the current active inventory, the J-52-P-6B, the J-52-P-8B, and the J-52-P-408. These three models, along with the average operating time per engine in each model and the type aircraft employing the engine, are shown in the following table. Appendix A provides a listing of the squadrons using these engines as well as their homebase locations.

Engine Model	Avg. Operating Hours	Type Aircraft
J-52-P-6B	4,186	TA-4J, TA-4F, EA-4F
J-52-P-8B	2,767	TA-4J, A-4E, A-4F, OA-4M, EA-6A, A-6E, KA-6D
J-52-P-408	1,533	A-4M, A-4F, EA-6B

Over 1200 J-52 engines are required "just to fill the slots" of the aircraft using this engine. The Naval Aviation Maintenance Program (8) authorizes three levels of repair for the J-52 engine according to the complexity and time required to accomplish repairs. Currently, 47 designated repair sites are authorized to perform some level of repair ranging from minor to complete teardown and major repair. These sites include CONUS as well as overseas and carrier-based repair facilities (9). Appendix B provides a listing of these repair sites.

The primary responsibility for repair of the J-52 engine lies with the Intermediate Maintenance Activity (IMA). This placement of responsibility is largely a result of policies established by the Engine Analytical Maintenance Program (EAMP), which was implemented in 1978 (8). The EAMP is primarily concerned with the establishment of maintenance requirements which enable engines to perform their task with a specific probability of success at the lowest possible total cost for system operation and support over the life cycle of the engine (8: Vol. III, 3-3-3).

Prior to the EAMP, engines were removed from the aircraft not only for failures, but also for overhaul at a depot facility on a scheduled basis. At that time, extensive preventive maintenance was performed, and known discrepancies were repaired. For engines now falling under the EAMP concept, however, there are no longer any scheduled overhauls at the depot facility. Engines are removed only for failures or for the accomplishment of certain maintenance actions by the IMA. These actions may include inspections, modifications, or investigations of sustained poor performance as directed by the appropriate command authorities (8: Vol. III, 3-3-3). The services of the depot facility are required only when a repair job is beyond the capability of intermediate level repair.

The Navy's policy in engine management is to maintain sufficient spare aircraft engines to support established peacetime operating objectives as well as mobilization and emergency requirements (10:1). "Engines will be managed economically and in a manner consistent with peacetime support requirements. This requires that the lengths of time of engine pipeline elements such as awaiting transit, in transit, awaiting rework, and in-process repair be reduced (10:1)." Pipeline elements are those stages through which an engine passes as it goes through the repair cycle. These stages include transit, storage, repair, awaiting-parts, and awaiting-maintenance.

Standard pipeline times for all Naval aircraft engines are established (10). The table which follows shows the standard times established for the J-52-P-8 and the J-52-P-408. These two models represent over 75% of the J-52 engines in service. The data in the table (in calendar days) is broken down by major elements of the pipeline and the site from which the engine originated. An engine originating, for example, at the organizational level ("O" Level) should experience (according to the standard) an average repair turnaround time of 26 days. Similarly, an engine going from a third degree facility to a higher level facility for repair should experience an average total amount of time of 25 days in the pipeline.

CONUS SITE OF ORIGIN

	"O" Level	3rd Degree	2nd Degree	1st Degree
Administrative Processing	2	2	2	2
In-Transit	5	4	3	0
In-Process Repair	19	19	19	19
TOTAL	26	25	24	21

One of the goals of the J-52 intermediate level repair system is to minimize pipeline time and maximize engine availability (21; 38). In a very broad sense, pipeline time (a term used synonomously with turnaround time) begins once an engine requiring maintenance has been removed from the aircraft. It ends when the engine has been returned to a serviceable condition and delivered to an operating squadron (38). The two goals or measures of performance - pipeline time and engine availability - are complementary. Shortening the amount of time an engine spends in the repair cycle results in engines returning to use quicker to satisfy a demand for a serviceable engine. Thus availability is increased.

The ability of the J-52 repair system to supply the fleet with serviceable engines in a timely manner, particularly under conditions of fluctuating demand, translates directly into strategic mobility. Likewise, a sluggish repair system frought with backlogs and delays tends to degrade the capability to respond quickly to a crisis. Sable provides this definition of strategic mobility:

> Strategic mobility is the player which translates combat force potential into combat force capability; the capability to deter and the capability to carry out a flexible response (34:44).

Meeting engine availability goals is essential for the successful accomplishment of the Navy's strategic mobility objectives. The entire logistics support system for the J-52 must be capable of meeting a surge demand as would be encountered in wartime. Failure to do so would result in a potential chokepoint in the logistics system and become a limiting factor in the ability to respond to a crisis.

Strict control of engine assets is essential in order for managers to be aware of pipeline time and spare engine availability. Without a knowledge of the factors causing engine delays in the pipeline, it becomes difficult, if not impossible, to forecast spare engine availability, particularly under the uncertain conditions of wartime. When this condition occurs, it seriously hampers the efforts of defense planners to develop wartime or crisis contingency plans. Thus, it is clear that the Navy's intermediate level repair system becomes a focal point of interest.

Statement of the Problem

Despite the standard established for turnaround time, the repair system for the J-52 engine is not performing as desired. Turnaround time (TAT) has increased significantly in the last four years, as seen in Figure 1 (see Appendix C for data). The dotted line between the FY-82 and FY-83 data points indicates that the TAT for FY-83 is an estimate since the actual figure was not available. It is still clear, however, that TAT has experienced almost a fourfold increase in four years.

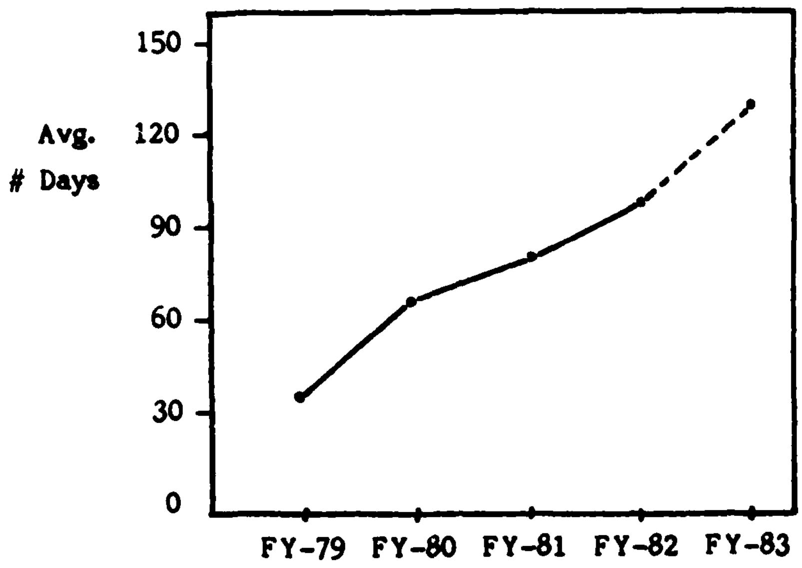


Figure 1. J-52 IMA Engine Turnaround Time (11:2)

This increase has had detrimental effects on J-52 engine availability. "Turnaround time has increased so much with so many engines in the pipeline that we do not have the spares we need, and we are not ready for mobilization under these conditions"(21). It seems clear that there is a need to examine those elements of the pipeline causing delays in the repair cycle in order to get the turnaround time back down to the standard.

To acquire data on the full impact of this degraded repair posture, the Aircraft Intermediate Maintenance Support Office (AIMSO) at Patuxent River, Maryland, conducted a study to identify factors which were contributing to the problem of an increase in the number of engines in the pipeline and a lengthened turnaround time. The results of the study are contained in a report issued by the AIMSO (11). This report, along with several interviews with engine managers, identifies the following contributory factors:

1. Awaiting Parts (AWP) time has shown an increase over a four year period, causing engines to wait longer in the repair system before being returned to use. (See Appendix D).

2. Thirty-one IMA sites transferred a total of 291 engines over a four year period to another repair site for repairs which could have been accomplished at the original location. Reasons for the transfers were not provided by the report. (See Appendix E).

3. The age of some of the older J-52 engines is causing the pipeline quantity to grow (38). Failure data, according to the Naval Engineering Support Office (NESO) at Jacksonville, Florida, indicates that the two older models (P-6B and P-8B) have reached the "wearout" phase in their life cycle (See Appendix F). Commensurate with this phase is a higher failure rate for these engines resulting from the deteriorated material condition and degraded engine performance (28). Thus, a higher failure rate has served to feed engines into the repair cycle at a higher rate, causing the pipeline quantity to grow.

4. The deteriorating quality of engine repairs was also suggested as a factor contributing to the growth in the number of engines in the pipeline (11:5; 21; 38). Data from the AIMSO report indicates that over a four year period 4,248 engines were repaired. Of these, 20% (835) were subsequently removed from the aircraft and re-submitted for repair prior to fifty operating hours. While no interpretation of repair quality was provided, nor any link established between these removals and repair quality, the data does suggest an investigation is warranted to determine if repair quality is, in fact, contributing to pipeline growth.

In summary, the factors contributing to pipeline growth are many and have resulted in a degraded repair posture for the J-52 engine. "These factors having an impact on pipeline growth can be lumped under inefficiencies, deficient training, inadequate repair system organization, and insufficient on-hand spare parts availability" (21).

The Navy's response to finding a solution to this problem has been to conduct a site consolidation study (30). The objective of the study is to determine if consolidation of selected repair sites will improve the J-52 repair support posture by decreasing pipeline time and, hence, increasing engine availability. Phase I of the study (Preliminary Analysis) has been completed. Phase II (In-Depth Study) is in progress at this time.

Regardless of the approach taken, it would appear that any proposed solution must be supported by an accurate model of the J-52 pipeline. The model must be able to identify the various elements of the pipeline where excessive time accumulation occurs as a result of such items as backlogs, shortages of resources, or inefficiencies. The model must also be able to examine changes in pipeline time as certain input levels (resources) are manipulated.

Research Objectives

The objectives of this research project were twofold. First, a network simulation model was constructed which replicates the J-52 intermediate level repair cycle as closely as possible. The model focusses on turnaround time (TAT) as the primary measure of performance of the repair system. The input factors for the model are the main resources available to the repair system: repair crews and engine workstands. Second, the operation of the model was verified. The times for the various processes in the repair cycle were estimated as well as the probabilities associated with the occurrence of the processes. Then the model was coded and run on a computer to demonstrate its performance.

Research Question

The following research question sets the direction for this project:

> Can a network simulation model be constructed which would accurately represent the J-52 repair cycle and provide a decision-making tool for managers in analyzing pipeline time?

In carrying out the research for this thesis project, obtaining answers to the following investigative questions aided in answering the main research question:

- What are the major elements, or processes, of the J-52 repair cycle pipeline?

- What relationships, if any, exist between these elements?

- Based on historical data, how many repairs undergo each process identified above?

- Which network simulation technique best describes the J-52 repair cycle?

- How do the input factors (resources) influence the output measures of performance (turnaround time)?

Scope and Limitations

The following are some of the constraints and limitations placed on this research project:

- The model replicates the pipeline associated with a first degree intermediate level repair facility.

- Only CONUS, shore-based facilities are considered, and not carrier-based or overseas facilities.

- Turnaround time is the only output measure being examined by the model.

- The relative merits of site consolidation (the alternative currently under investigation by the Navy) is not addressed in this project.

- No attempt is made to explain the reason for the existence of pipeline deficiencies causing extended turnaround times.

- The model does not address the details of the operation of a depot level facility. Even though engines occasionally pass through that portion of the pipeline, addressing changes in the structure and operation of a depot facility is extremely difficult because of the complexity of its operation. Thus, the model treats in detail only those portions of the pipeline where IMA managers have the greatest flexibility in making changes for improvement. The flow of an engine through a depot facility is treated only as a time delay in the pipeline.

Assumptions

Since this was a first attempt at a network model of the J-52 repair cycle, certain assumptions were made in order to simplify the construction and understanding of the model. These assumptions include:

- All like repair crews are equally skilled. Additionally, no distinction is made between skill levels of individual crew members.
- The quantity of resources available (repair crews and engine workstands) remains fixed over the period prescribed by the simulation.
- Parts are supplied through normal supply channels and not through cannibalization. (Cannibalization is the removal of needed parts from other engines undergoing repair when the parts are not readily available through normal supply channels).
- The IMA performs both unscheduled maintenance (repairs for failures), and scheduled maintenance (inspections and modifications).
- The IMA provides repair support for certain activities at remote CONUS locations as well as those in the immediate area.

Justification for the Research

Engine managers are accountable for the efficient and effective performance of the J-52 repair system. In many cases, however, this accountability is hampered by a lack of information regarding system performance (14:120). Given this absence of objective information, managers often must make arbitrary judgements about such crucial management issues as goal setting, personnel assignments, work schedule development, and resource allocation. The resulting situation is often like navigating in a fog with no compass – decisions are made on intuition alone (2).

A simulation model will aid managers in decision-making by providing objective information about the repair cycle pipeline. Some of the possible gains include:

- Identification of areas in the pipeline where excessive engine backlogs occur.
- The ability to reallocate idle resources such as crews and workstands to the points where these backlogs occur.
- The ability to investigate alternative work scheduling plans to reduce pipeline time.
- Identification of inefficient processes in the pipeline where training or management attention is required.

II. Literature Review

Chapter Overview

Before proceeding with the model development in Chapter III, it is appropriate first to consider the literature on the system being modeled as well as the simulation techique employed. A discussion of the intermediate level jet engine repair cycle is presented first. This discussion begins with the broader issues of aviation maintenance addressed by the Naval Aviation Maintenance Program (NAMP), and eventually focusses on specific NAMP concepts which govern jet engine maintenance. Following this, some specific applications of simulation modeling are provided. These applications relate not only to simulation in general, but also to the specific simulation technique employed in this project. Uses of simulation in both the commercial and the D.O.D. sector are addressed.

The Naval Aviation Maintenance Program (NAMP)

Description of the Program. The NAMP is an integrated system for providing maintenance and all related support functions on aeronautical equipment (8: Vol I, 1). The program is sponsored and directed by the Office of the Chief of Naval Operations (CNO) and serves as the ultimate authority for matters pertaining to the maintenance and support of Naval aeronautical equipment. Formally established on 26 October 1959, the NAMP has undergone several periodic revisions in order to stay abreast with the changes in complexity of modern Naval jet aircraft. The current version, OPNAV

Instruction 4790.2B, was issued in 1977 and serves as a guide for aviation maintenance managers at all levels.

Policies established by the NAMP are carried out by the Chief of Naval Material via the Commander, Naval Air Systems Command (NAVAIRSYSCOM) in Washington, D.C. As the coordinating authority for the conduct of the NAMP (8: Vol.I, 1-3-6), NAVAIRSYSCOM's duties include:

- Providing guidance on all aviation maintenance policies and procedures addressed by the NAMP, and

- Providing technical direction and management review of the program at all levels of maintenance.

Objectives of the NAMP. The primary objectives of the Naval Aviation Maintenance Program are twofold:

- To achieve and maintain the material condition standards for aeronautical equipment as directed by the Chief of Naval Operations, and

- To fully support the CNO safety program.

Both of these objectives are to be accomplished while minimizing total resource requirements (8: Vol I, 2-1-1).

The Three-Level Maintenance Concept. To carry out these objectives, the NAMP employs the three-level maintenance concept as established by the Department of Defense. Repairs on aeronautical equipment are to be performed at that level of maintenance which ensures optimum economic use of resources (8: Vol I, 2-1-1).

The lowest level of repair is referred to as organizational maintenance. This involves the upkeep maintenance functions performed by an operating unit on a day-to-day basis in support of its own operations. These functions normally include inspections, servicing, equipment handling, on-equipment corrective and preventive maintenance, tasks assigned by technical directives, and routine record keeping and report preparation.

The next level of repair is referred to as intermediate maintenance. This encompasses the repair of aeronautical equipment in support of user organizations. Its functions normally consist of calibration, off-equipment repair or replacement, the manufacture of certain non-available parts, the accomplishment of certain periodic inspections, and the provision of technical assistance to user organizations. These functions are generally held to be beyond the capability of operating units.

Depot maintenance is the highest level of repair authorized. This refers to rework maintenance performed on aeronautical equipment requiring major overhaul or a complete rebuilding of parts, assemblies, and subassemblies. Depot maintenance functions include the manufacture of parts, modifications, testing, and reclamation as required. These facilities support the lower categories of maintenance by providing engineering assistance and by performing maintenance that is beyond the capabilities of the lower level facilities.

The three-level maintenance concept provides certain management capabilities (8: Vol I, 1-1-1). These include:

- The classification of maintenance functions at a specific level,
- The assignment of maintenance tasks consistent with the complexity, depth, and scope of work to be performed,
- The accomplishment of a particular task at a level which will ensure optimum economic use of resources, and
- the collection, analysis, and use of pertinent data to assist all levels of management concerned with the NAMP.

The Intermediate Level of Maintenance. This project is concerned primarily with the intermediate level of maintenance. Thus, certain aspects of this level are examined further.

An Intermediate Maintenance Activity (IMA) comprises all departmental units responsible for providing intermediate level maintenance support ashore and afloat. A shore-based IMA normally consists of the following departments:

- Aircraft Intermediate Maintenance Department (AIMD),
- Supply Department,
- Weapons Department,
- Public Works Department.

Of these four, the AIMD is responsible for performing intermediate level maintenance functions on aircraft and aeronautical equipment.

The AIMD is authorized to perform only those maintenance functions specified by the NAMP for intermediate level repair. To determine if a repair can be undertaken, the AIMD consults the appropriate Maintenance Instruction Manual (MIM) to determine the functions required to accomplish the repair. If a function falls beyond the capability of the AIMD, the equipment is sent to a higher level activity for repair.

Since the intermediate level repair for engines is the focal point for this project, it is appropriate to consider the maintenance functions which may be performed by the Powerplant Division of an AIMD. According to the NAMP (8: Vol. III, 1-1-6), the following intermediate level repair functions may be performed on powerplants and related systems:

- Periodic Inspection (engine installed or removed),
- Functional test and adjustment utilizing engine run-up stand,
- Repair of engine systems and components,
- Repair of removed auxilliary power units, and
- Preservation and depreservation of uninstalled engines.

The Three — Degree Gas Turbine Engine Repair Program. The repair of jet engines at the intermediate level is governed by the Three-Degree Gas Turbine Engine Repair Program. Operating under the jurisdiction of the NAMP, this program provides the policies and procedures for the accomplishment of engine repairs by the Powerplants Division of AIMD. This program is contained in NAVAIRSYSCOM Instruction 13700.10 series.

Under the Three-Degree Gas Turbine Engine Repair Program, each intermediate level jet engine maintenance manual defines specific maintenance actions as either first degree, second degree, or third degree functions. These maintenance functions are determined largely by the degree of difficulty and recurring frequency (8: Vol. III, 3-3-1). Selected IMA's are assigned to provide a specific degree of support for certain engines. This assignment is based primarily on the type and number of engines supported within the geographical region.

Beginning at the lowest level, third - degree repair encompasses primarily certain engine inspections. It also includes some minor repair functions which have a high incidence rate but low maintenance manhour requirement. Second-degree repair refers to the repair of discrepant gas turbine engines which normally require the repair and/or replacement of turbine rotors, combustion section components, and afterburners. Maintenance on the compressor section is limited to minor repairs. First-degree repair refers to the repair of discrepant engines which require compressor rotor replacement, and/or disassembly to the extent that the compressor rotor could be removed. Additionally, any repair requirement that goes beyond the capability of a second-degree facility but does not require depot level repair is defined as first-degree repair.

The Engine Repair Cycle Pipeline. The final topic pertaining to the Naval Aviation Maintenance Program addresses the flow of an engine through the repair cycle pipeline. Two viewpoints are provided along with a graphical illustration of both. The first viewpoint, shown in Figure 2, represents the interaction of the three levels of maintenance from a macro perspective. The three levels of maintenance, as mentioned previously, are the organizational, intermediate, and depot level. (The Supply Support Center is included in the figure because of its central role in controlling engine movements, although it is not to be confused with the three levels of maintenance).

According to Figure 2, engines declared "not locally repairable" at the organizational level are turned in to the Supply Department and a replacement is issued from the spare engine pool if available. Supply then inducts the retrograde engine into the IMA for repair. The IMA either repairs it, or sends it to a facility with higher level repair capability. The dashed line between the IMA and the Supply Support Center indicates communication of the engine status and coordination for shipping of the engine to another facility for repair. Eventually, the repaired engine is returned to the spare engine pool for subsequent issue as required.

In reality, the actual flow of engines is made much more complex by factors not revealed in the figure. In the case of the J-52, for example, bases rarely experience the luxury of an actual spare engine pool. The demand for serviceable engines as well as the growth of the repair pipeline (as discussed in Chapter 1) have necessitated a tightly controlled policy for assignment of serviceable engines (24). Many engines experiencing a failure and receiving repairs at one base will often be assigned to fill a demand at some remote location rather than staying at the original base. These engine assignments are made in accordance with guidance from higher echelon management.

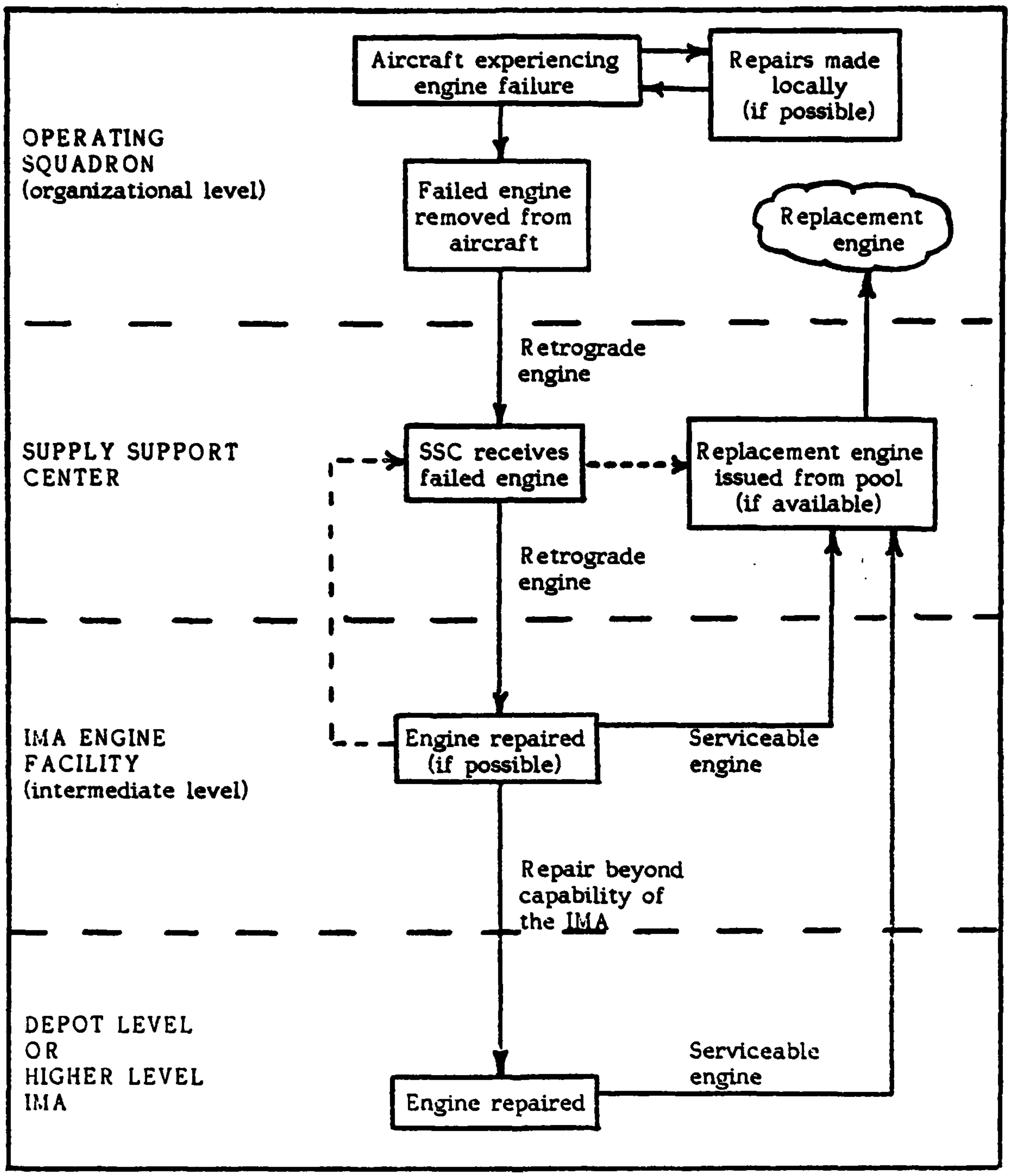


Figure 2. The NAMP Three-Level Concept (8:Vol. II & III)

The second viewpoint, shown in Figure 3, illustrates the flow of an engine through the repair cycle again, but in more detail. The flowchart describes from a micro perspective the key decisions and processes at the intermediate level of maintenance which govern the particular path an engine will take. The heavy dark lines indicate engine flows, while the dashed lines indicate a communication link between two points.

From the flowchart, all engines inducted into the IMA for maintenance require either scheduled or unscheduled maintenance. The first decision made is whether or not the required maintenance is within the IMA's capability. If it is, a decision is made as to whether a pre-induction test cell run is required of the engine in order to troubleshoot the discrepancy further before attempting repairs. If the engine is not repairable locally, it is forwarded to a higher level IMA facility or to the depot facility.

Once an engine is inducted for maintenance, it will require either major or minor repair. Major repairs have substantially greater requirements than minor repairs, both in the preparation stage and the actual repair stage. Regardless of the extent of maintenance required, however, engines may incur Awaiting Parts time (AWP) or Awaiting Maintenance time (AWM). These involve, respectively, time delays associated with acquiring needed parts or with tending to other maintenance matters.

The flowchart indicates that engines may need to have QEC components removed prior to performing maintenance on the engine. QEC (Quick Engine Change) components are certain externally mounted items on the engine which serve to adapt the engine to a particular aircraft. The components include such items as hydraulic pumps, oil drain lines, and certain electrical components. Removal of these items is often, but not always, necessary to facilitate maintenance on the engine.

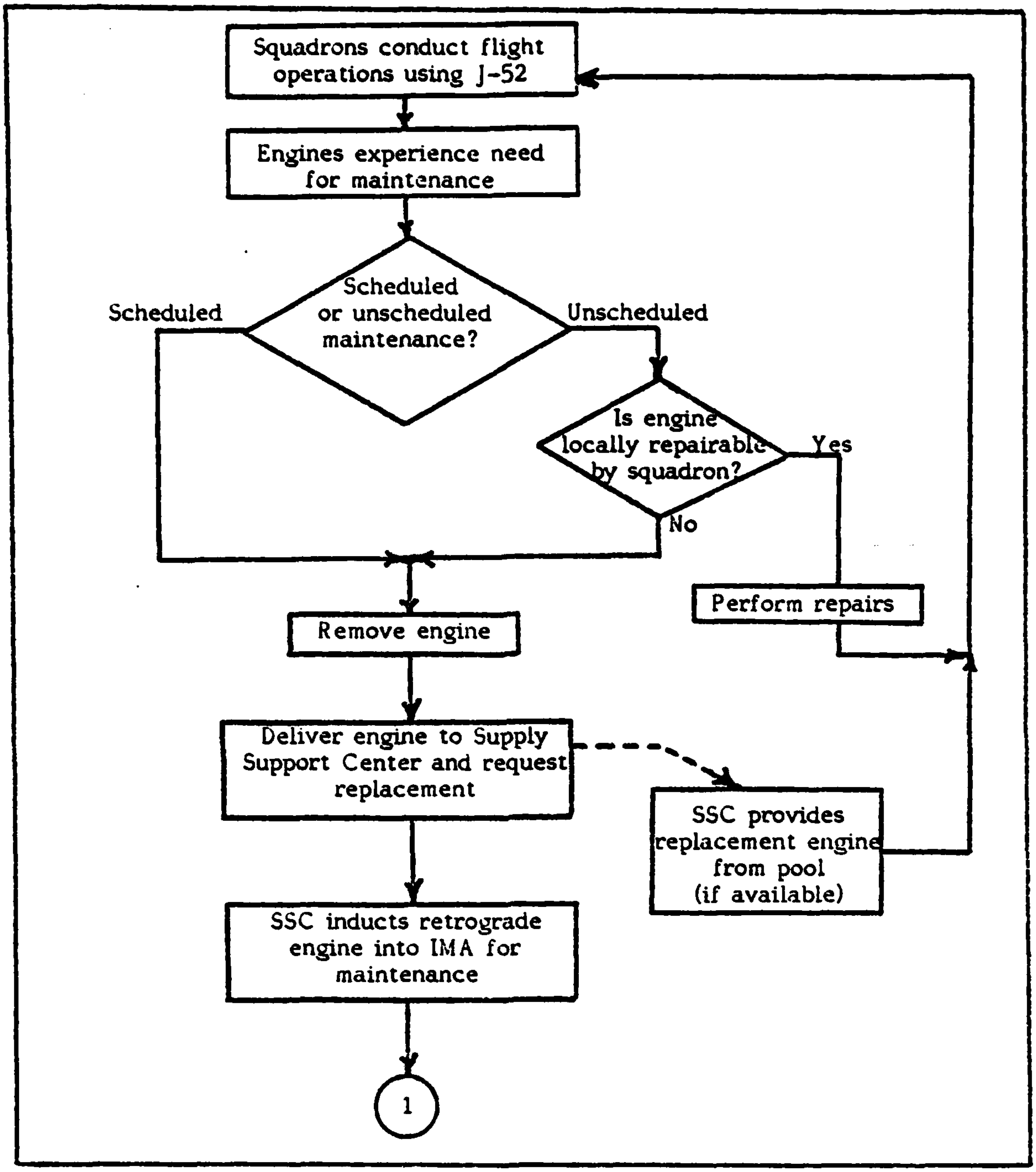


Figure 3. Flowchart of the Intermediate Level Repair Cycle Pipeline (8:Vol. III)

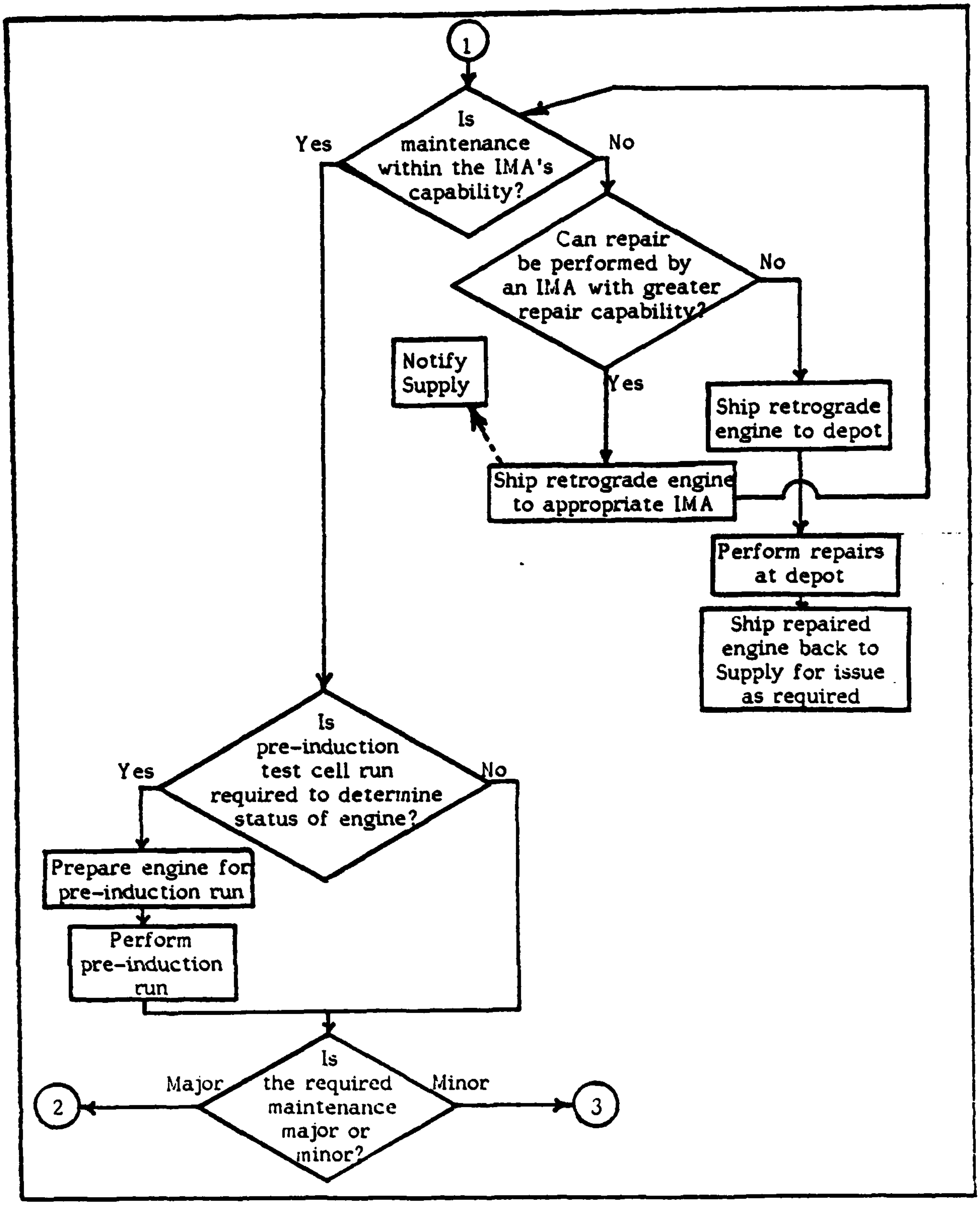
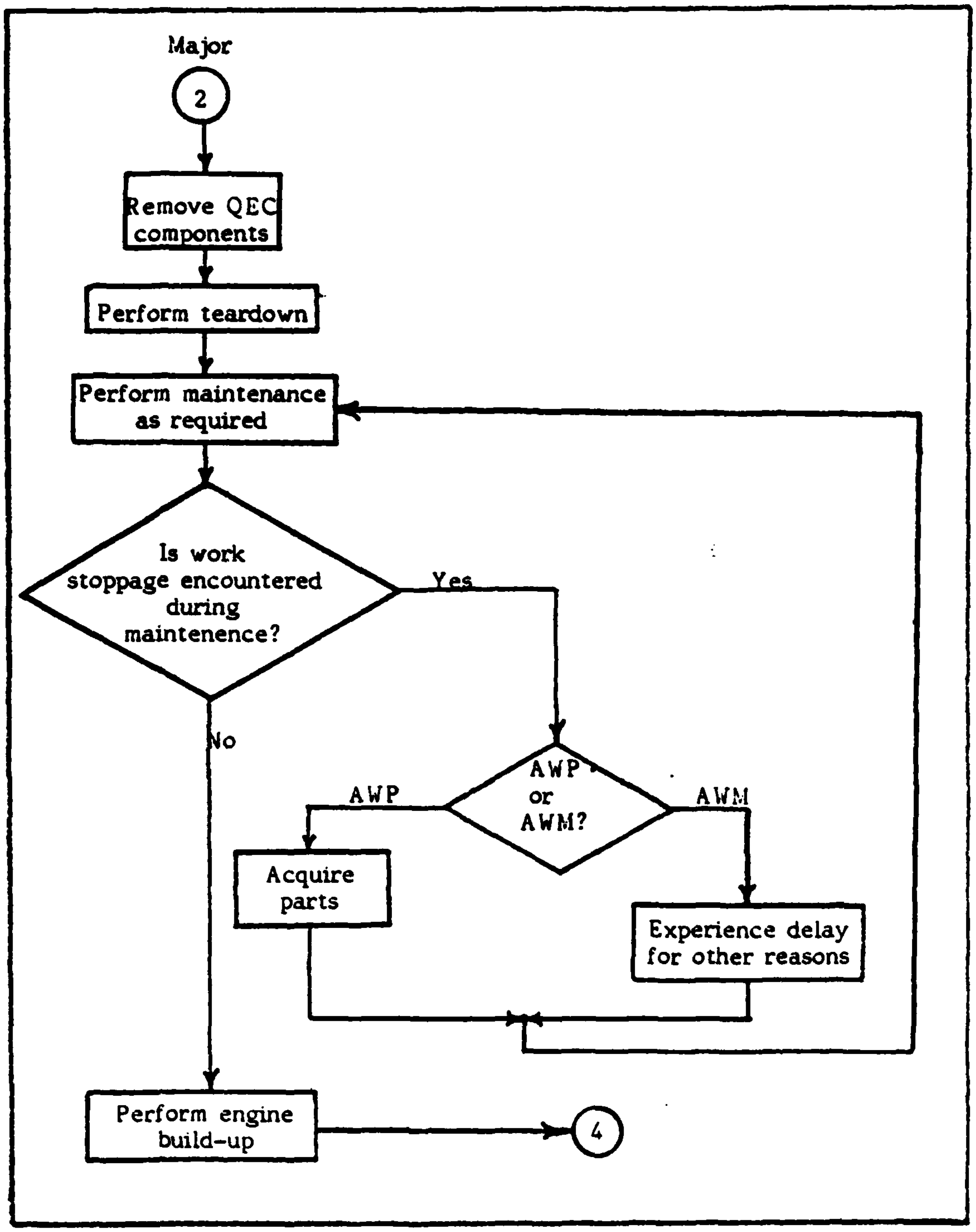


Figure 3. (continued)



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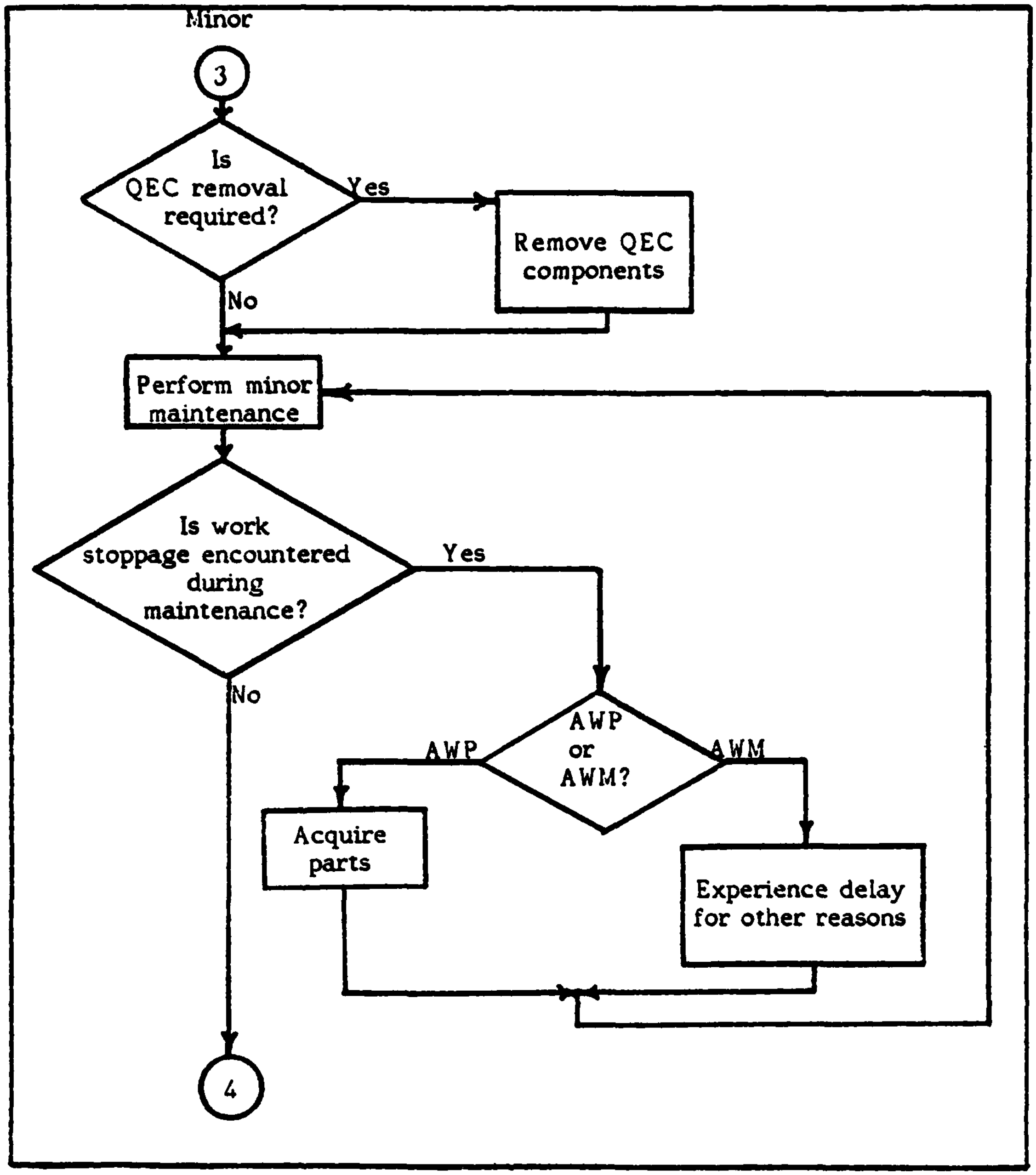

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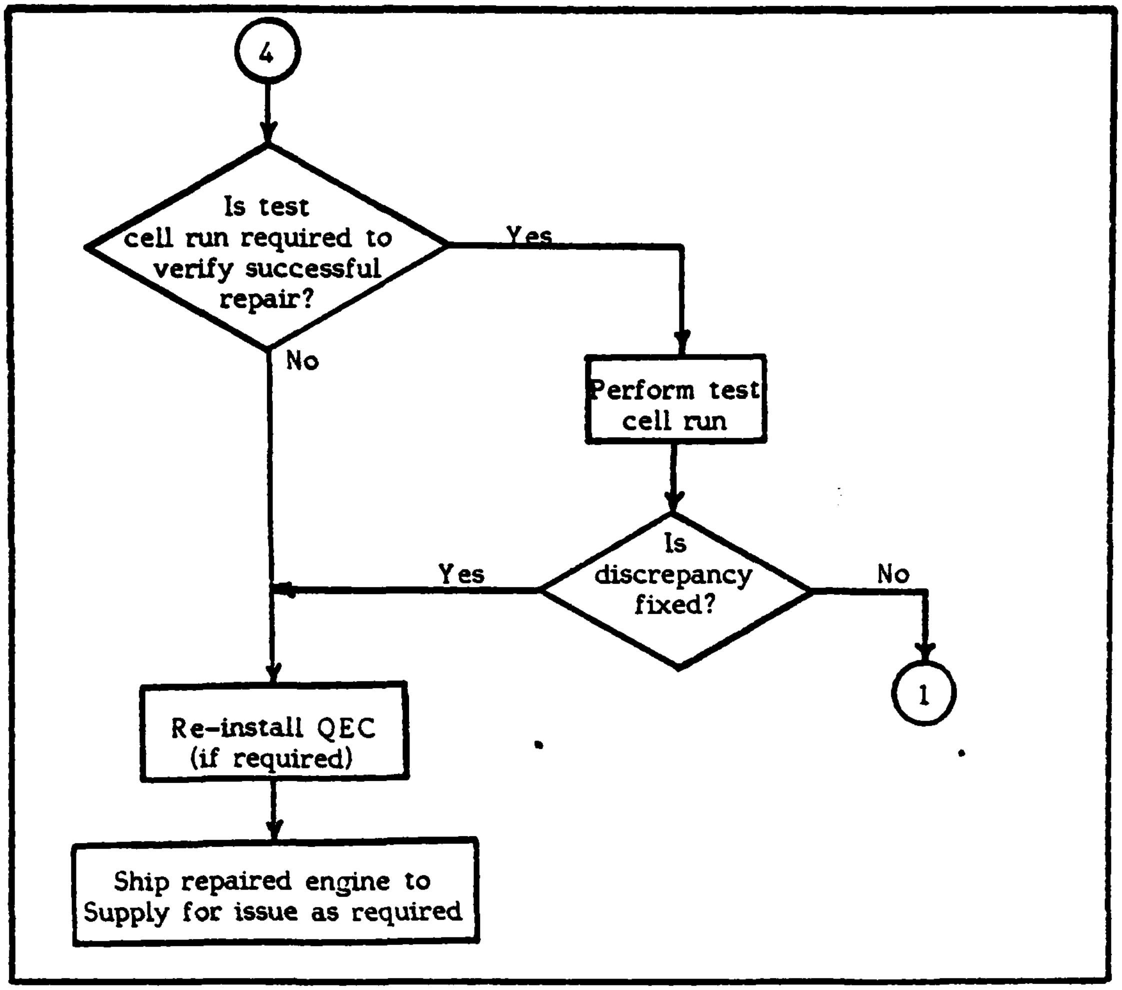

Figure 3. (continued)

Once maintenence on the engine is complete, a determination is made as to whether a test cell run is required to verify that the engine is, in fact, serviceable and RFI (Ready For Issue). If the discrepancy persists after a test cell run, further investigation is required to determine if the engine can still be repaired locally, or whether it must be sent to a higher level facility. RFI engines are returned to the Supply Support Center (SSC) for issue to fill the next demand.

Applications of Simulation

Having presented a brief overview of the structure and key concepts of the intermediate level maintenance program, attention is now turned to applications of simulation modeling. The few applications mentioned in this section provide only a representative sampling of how managers are using this approach in studying and analyzing various systems in the heart of many industrial and social organizations. First, some general areas where simulation has been applied is discussed. Following this, some specific areas where Q-GERT has been applied are also discussed.

Q-GERT was selected as the simulation language most appropriate for this project as a result of its capability for modeling queueing situations such as those encountered in the J-52 repair system. Appendix G provides a substantive discussion on the background of modeling and simulation as well as the justification for employing Q-GERT in this project. For more detailed information on Q-GERT, the reader is referred to Appendix H which describes Q-GERT network symbology.

General Areas. As a result of its ease of manipulation and the advantages gained over direct experimentation, simulation has been applied in a number of different settings. Countless articles and books on the topic attest to its widespread popularity. Applications of simulation, for example, can be found in the fields of business (16; 26; 29), politics (5), behavioral science (20; 37), transportation (23), and numerous other fields. Day and Hottenstein (7) list some general areas where effective use of job shop simulation has benefitted management. These include the ability to forecast shop workload, the planning of shop layout, the scheduling of critical resources, and the testing of various sets of operating decisions.

GERT, the family of simulation languages to which Q-GERT belongs, is only one of the techniques available for simulation, and is applied in various settings. Elmaghraby (13:323) comments that GERT simulation has been used to model and analyze contract-bidding situations, population dynamic behavior, maintenance and reliability studies, vehicle traffic networks, accident causation and prevention, computer algorithms, and many other areas of investigation too numerous to mention. GERT simulation has also been successfully applied to industrial sales negotiations and cost planning for corporate level decisions (3; 32).

Specific Q-GERT Applications. The focal point of interest for this section on application is on the specific areas in which Q-GERT has been applied. One of many examples is found in the transportation industry, particularly in intermodal transportation.

Intermodal transportation refers to shipments of freight between two locations in such a manner that two or more modes (truck, rail, air, ocean vessel) participate in the movement to accomplish its delivery. Increases in the use of intermodal transportation is very probable in the future and is "very much dependent on the development of new technology for both the intermodal terminal areas and transportation methods (18:55)."

To this end, Hammesfahr and Clayton (18:55-68) conducted a computer simulation study to determine ways of improving efficiency in intermodal terminal operations. The three primary areas of concern in this study were as follows:

- At what level of demand for intermodal traffic would the terminal facilities become saturated?
- What scheduling or procedural changes in existing operations would result in greater efficiency?
- Can efficiency be improved and cost-effectiveness be maintained by relocating and modifying existing facilities, or by acquiring additional support?

The primary tool for this study was a Q-GERT network model which facilitated the simulation process and avoided the need for direct experimentation at the terminals which would cause disruption of service. The model aided in the analysis of parking lot requirements, alternate loading/off-loading procedures, alternate ramp procedures, capacity requirements for ramps, ports and sidings, proposals for new facilities, and measures of terminal performance. Because of its graphical nature, Q-GERT offered an ideal method of visualizing the flow of transactions (trucks, ships, etc.) through the system. It also enabled managers with limited simulation experience to obtain a reasonable and comprehensible understanding of a complex system.

Q-GERT has also had an impact in the D.O.D. as well. A study was conducted to develop a Q-GERT simulation model of the supply requisition processing functions at the Naval Supply Center, San Diego, California (15). The objective was not only to identify the most efficient means of routing a requisition through the system, but also to pinpoint backlog problems and inadequate resources at each service activity. Through this study, management could identify the "best" allocation of resources within specified constraints.

Another D.O.D. application involved the use of Q-GERT to simulate the maintenance support requirements for avionics equipment on newly proposed weapon systems (25). This study yielded a model which provided managers with the informatiion necessary for determining the required level of resources (eg., manpower and test equipment) for supporting the avionics systems of new aircraft. A separate but related study (4) applied queueing theory in determining the proper quantity of test equipment required to support the F-16 avionics systems. By using Q-GERT modeling, the avionics component repair cycle for the F-16 was simulated and the authors were able to determine the optimal number of F-16 avionics test sets to acquire in order to achieve the greatest reduction in awaiting maintenance time.

Finally, a study was conducted to determine those factors that significantly affect an Air Force intermediate level propulsion branch's ability to provide a steady supply of spare aircraft engines. Using a Q-GERT model, the Base Level Repair process for the TF-33 P7/7A engine at a MAC base was simulated (6). Four critical factors influencing Mean Repair Time were identified and incorporated into the model. The objective of the model was to prescribe a resource allocation plan which would achieve the "best" measure of engine support.

Admittedly, the DOD applications described herein are the results of thesis efforts and do not reflect "tried and proved" methods in their respective areas. Nevertheless, considering the fact that Q-GERT is a relatively new tool which must gain further acceptance in the D.O.D. through proven applications, these studies do point out some of the possibilities where it can be applied. It is hoped that this Q-GERT simulation model of the J-52 intermediate level repair cycle will prove beneficial not only in studies of shore-based repair facilities, but also (through some further expansion) in studies of logistics problems associated with jet engine support aboard aircraft carriers.

III. Methodology

Chapter Overview

The purpose of this chapter is to describe the procedures followed in constructing a Q-GERT network simulation model of the J-52 intermediate level repair cycle. Two major phases characterized the work: performing an analysis of the J-52 repair system and constructing the network model.

System Analysis

The system analysis phase was guided mainly by the decision-centered approach (22:167) which dictates that the development of a management decision-making tool requires a thorough analysis of the problem situation in order to understand exactly which decisions the model is required to support. For this research project, the system analysis phase drew heavily upon three sources of information:

- Personal interviews with engine program managers,
- An on-site visit to an intermediate level repair facility, and
- Personal experience.

To assist in carrying out the system analysis phase, a field trip was scheduled to the engine headquarter offices in Washington, D.C., and to the Propulsion Branch of the Aircraft Intermediate Maintenance Department at Naval Air Station, Oceana, Virginia. (The facility at NAS Oceana is a first-degree repair facility in support of several squadrons using the J-52 engine. This facility was not modeled; rather, it simply served as a guide for answering general questions as the construction of the generic model progressed).

The purpose of the interviews with engine program managers was twofold. The first related to the output performance measure being examined by the model. Since turnaround time (TAT) was of primary interest in this project, information was needed on the standards for this performance measure as identified by engine program directives. The intent, therefore, was to identify the appropriate directives which provided this information.

The second purpose of the interviews was to discuss the operation of the J-52 repair system in general. The model treats the repair system in simple terms by imposing several limitations and by making some assumptions. Through interviews, a determination was made as to whether these limitations and assumptions were adequate. Also, the interviews served as a means of identifying any peculiar characteristics of the repair system which should be included in the model.

Having conducted the interviews, the next step in the system analysis phase was an actual on-site visit to an intermediate level engine repair facility. The actual repair process was observed in order to acquire specific information about the stages of repair. Other elements in the complete repair cycle pipeline were also identified. These elements have been identified as storage time, transit time between facilities, QEC romoval/installation, teardown, repair, awaiting parts and awaiting maintenance time, build-up, and test-cell operation. Pritsker (31:2) states "The success of a modeler depends on how well he can define significant elements and the relationships between elements."

Therefore, through direct observation, interviews with propulsion branch managers, and personal experience, these elements and their interrelationships were examined. In essence, the goal of this stage was to "walk through" the repair cycle and construct a prescriptive model of the J-52 repair cycle.

Model Construction

The final phase of this project was the construction of a model of the J-52 repair cycle pipeline based on information collected from the system analysis. The Q-GERT symbology (described in Appendix H) was employed and assigned to the appropriate points on the network model.

Validation of the model was not performed in this project (validation is discussed in Chapter V as a recommendation for follow-on research). The model's performance was, however, verified. Verification refers to the actual running of the simulation model on the computer to verify that it does, in fact, produce output. To accomplish this, it was necessary to estimate the distribution functions employed at various points in the network. Branching probabilities were also estimated. Inasmuch as possible, personal intuition and information obtained from the on-site visit were employed in deriving these estimates to replicate the actual repair process as closely as possible.

IV. System Analysis and Model Construction

Chapter Overview

The purpose of this chapter is to describe the construction of the Q-GERT network model of the U.S. Navy's intermediate level J-52 repair system. First, a system analysis is provided in order to describe the repair system under investigation. While a flowchart of the decision process was provided in Chapter II, the system analysis in this chapter provides a more in-depth look at the characteristics of the repair system. This analysis provides the setting for the actual construction of the network simulation model.

Following the system analysis, the model itself, shown in Figure 4, is described in detail. Although the operation of the intermediate level repair system is generally the same regardless of location, subtle differences do occur in local operating procedures and organizational structure. For this reason, it is necessary to formulate a scenario which describes some of the operating and structural characteristics of the system being modeled. The contrived system described in the scenario is not based on any particular existing facility. It simply provides a setting in which the model development can take place. The essential decisions and processes, however, are preserved in the generic model without loss of accuracy.

One final note is necessary to assist the reader in understanding the network model in Figure 4. The model spans six pages, and connectors are provided to enable the reader to trace the network from page to page without loss of direction. These connectors, which are the encircled letters, serve only as guideposts for the reader, and not as nodes in the network.

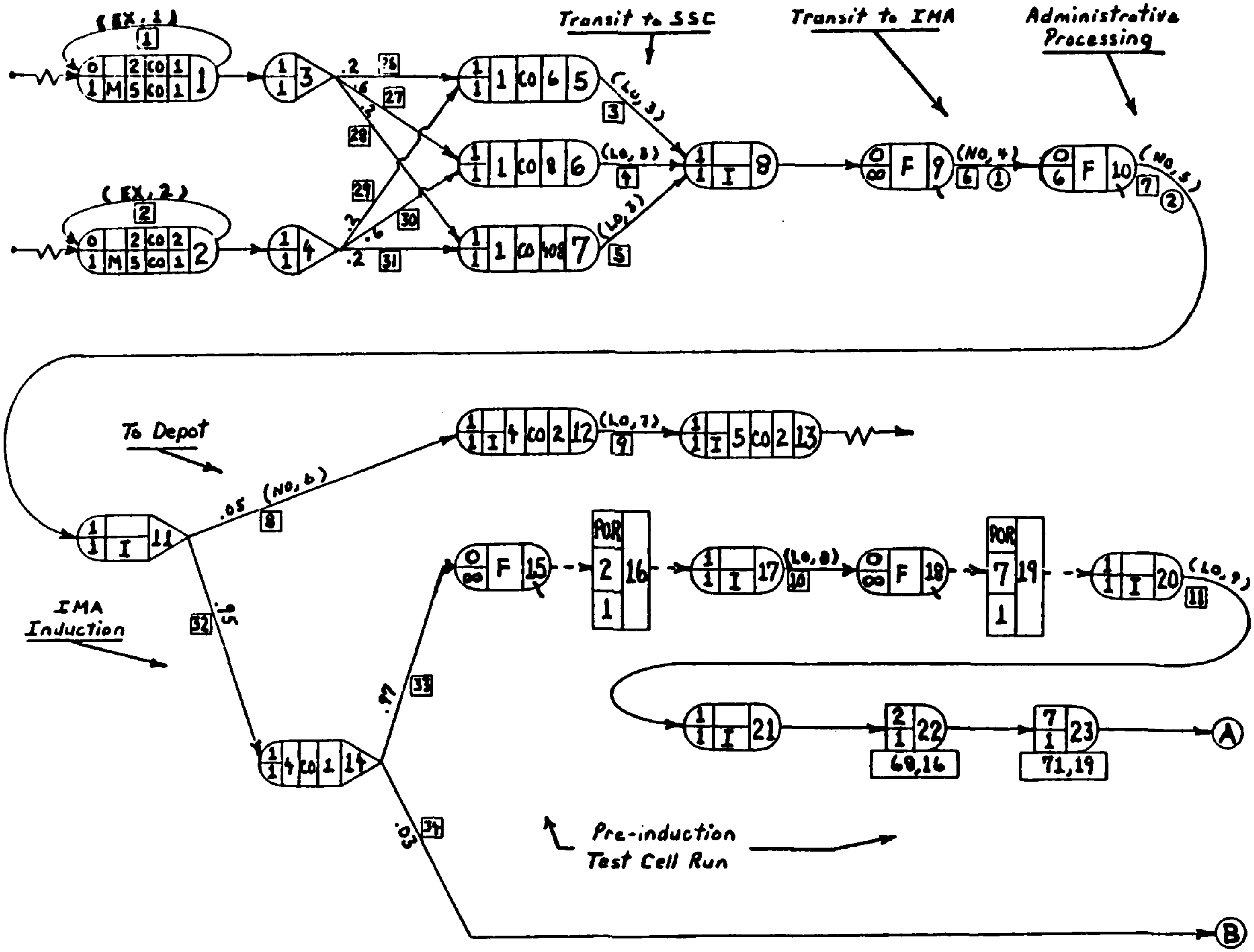

Figure 4. A Q-GERT Model of the J-52 Repair System

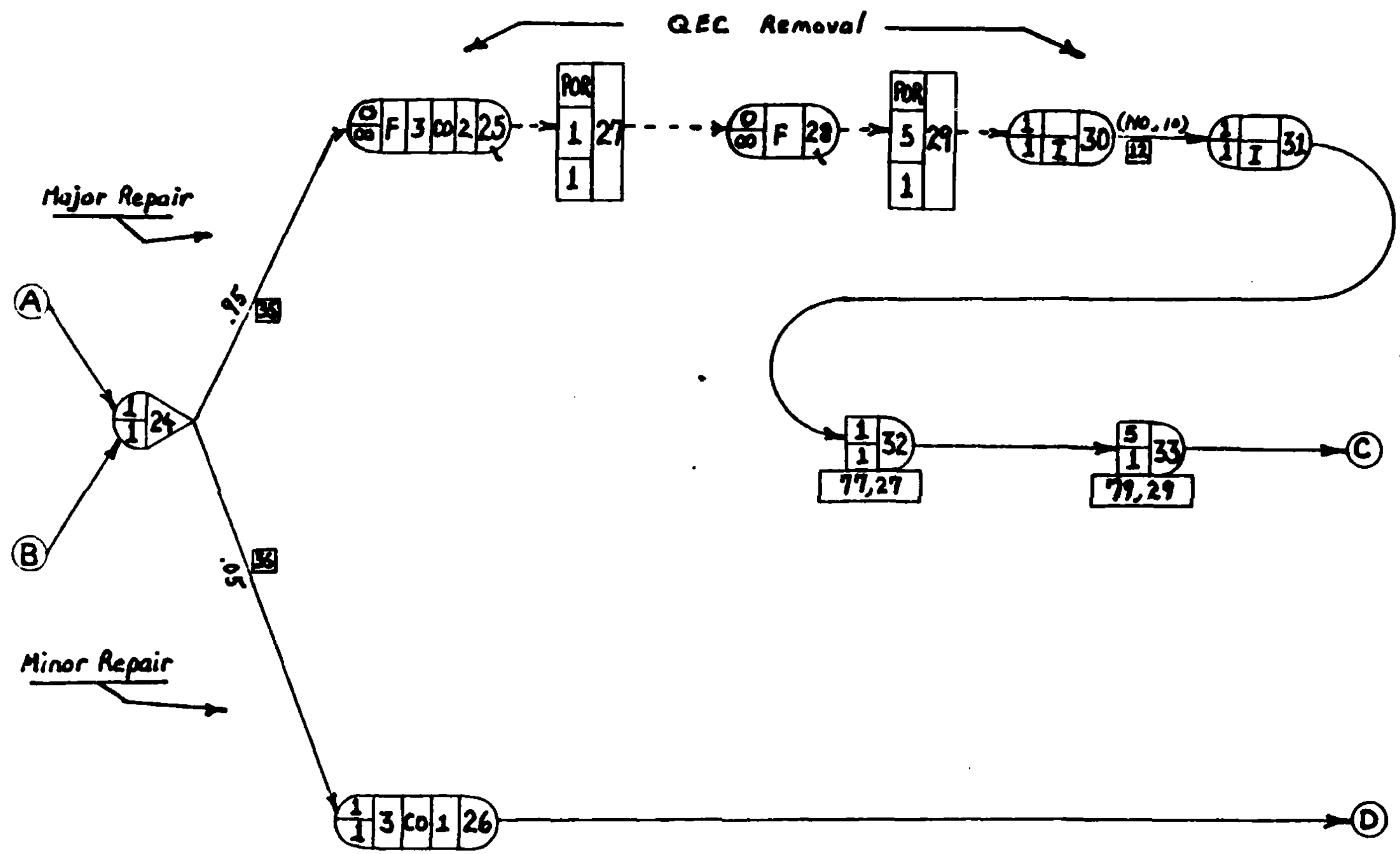

Figure 4. (Continued)

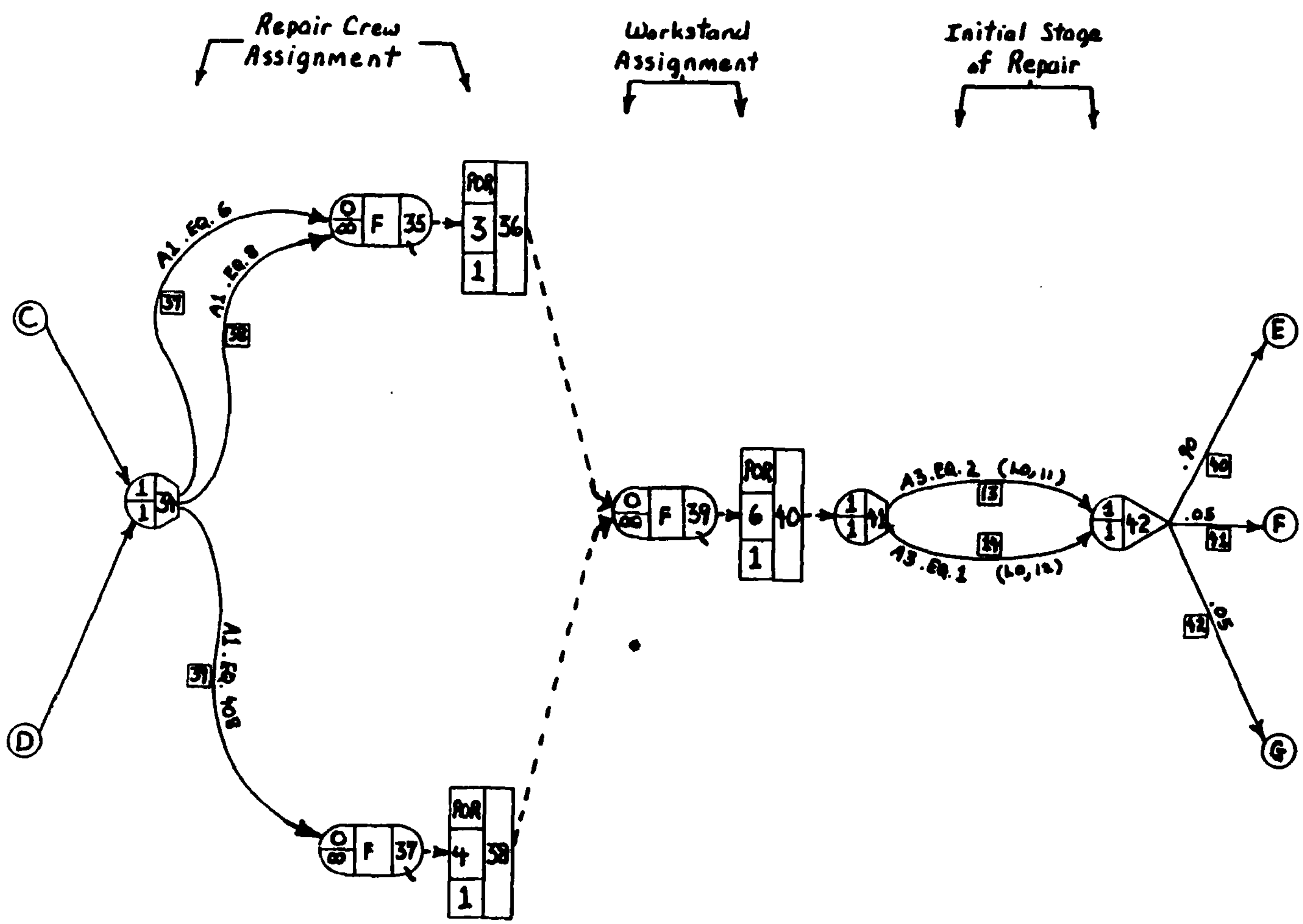

Figure 4. (Continued)

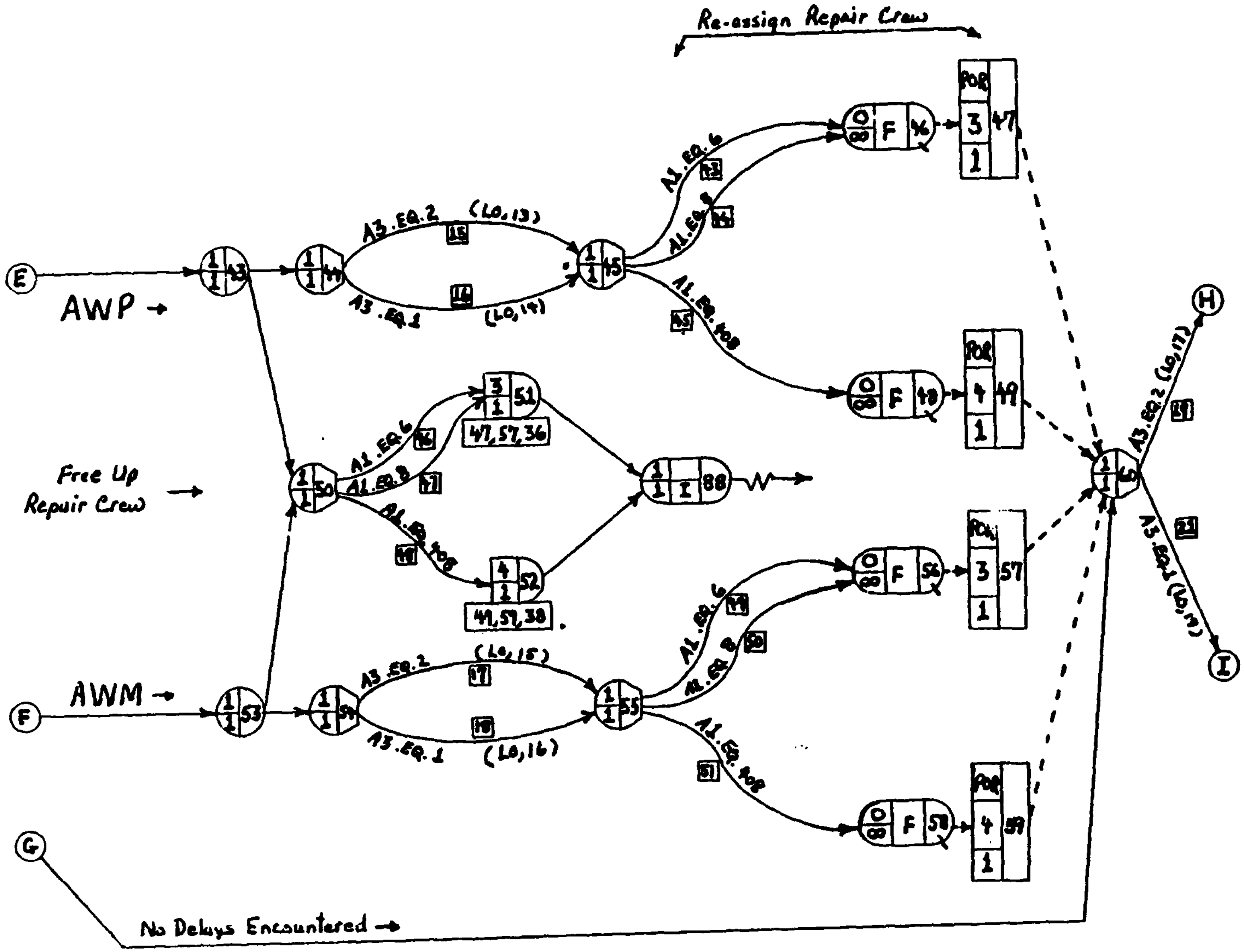

Figure 4. (Continued)

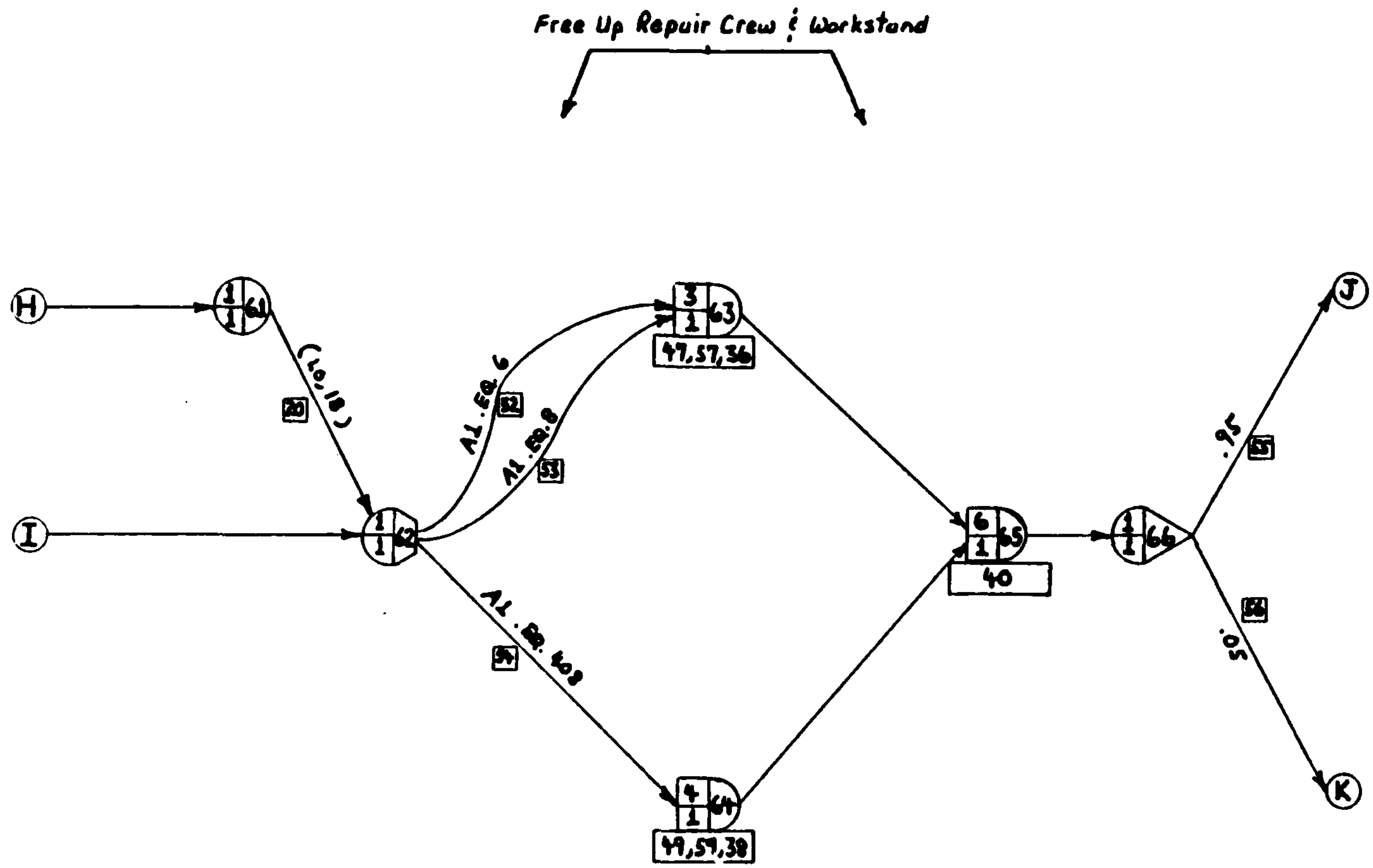

Figure 4. (Continued)

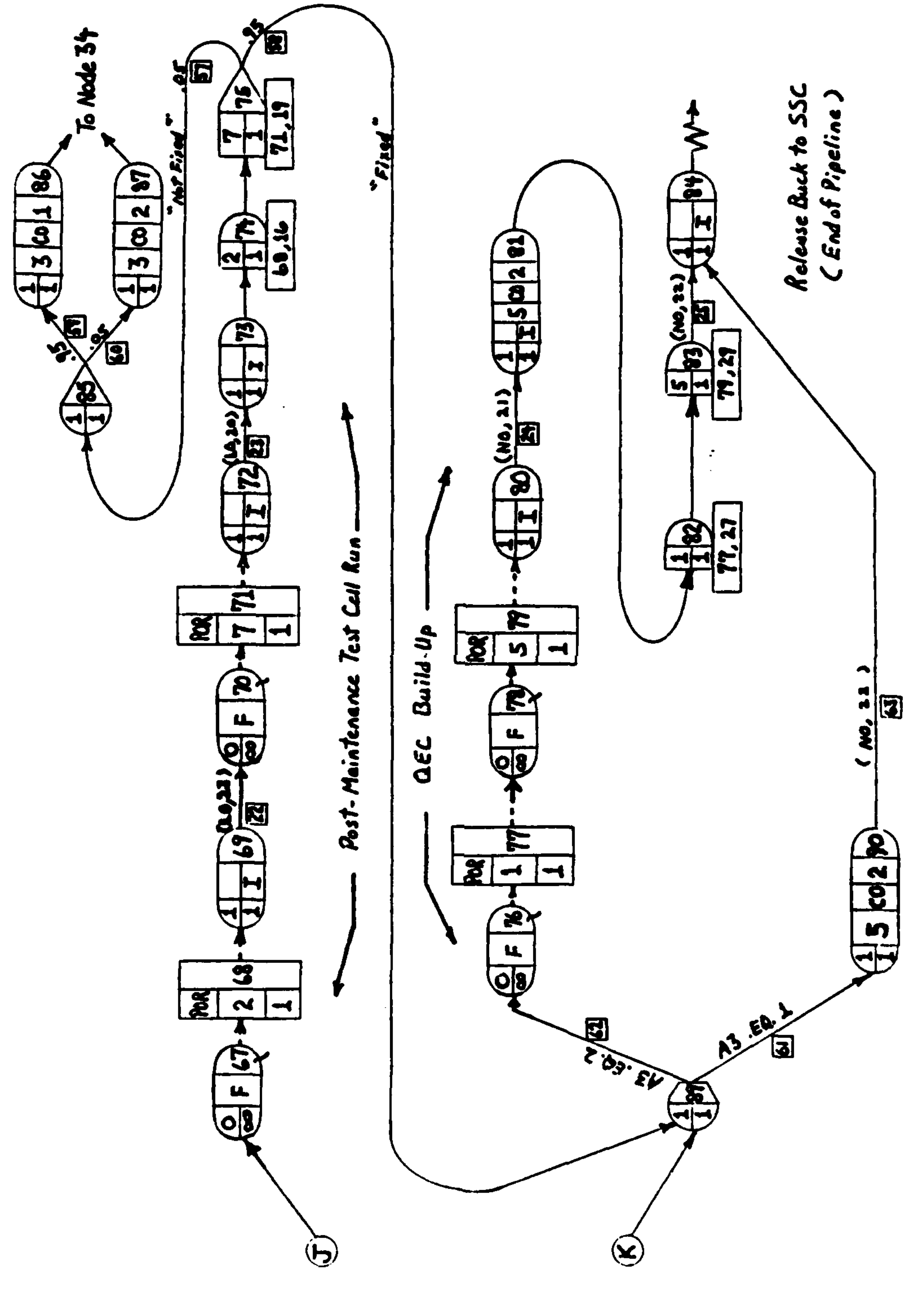

Figure 4. (Continued)

System Analysis

This section describes the composition and operation of the J-52 intermediate level repair system in a generic sense. An on-site visit to a first degree repair facility as described in Chapter III provided the background for this analysis. Interviews, direct observation, and personal experience are the source of all information presented in this section.

Organizational Composition. The typical first degree repair facility employs approximately 100 personnel, including mechanics, supervisors, managers, and admisistrative support personnel. Generally, the workforce is divided into three 8-hour shifts and operates five days a week. On weekends, only a small duty section performs repair services.

Certain resources are essential to the performance of jet engine repair. These fall mainly under the headings of crews and equipment. While slight differences in crew composition may occur from one facility to the next, a typical facility may include QEC (Quick Engine Change) component removal and build-up crews, repair crews, and test cell crews. Repair crews may even be sub-divided further by engine model.

The main equipment resources necessary for engine maintenance are workstands and test cells. Workstands include those necessary for QEC component removal and build-up as well as for actual repair. Generally, the QEC and repair sections of the facility are physically segregated as a result of the nature of the work involved. Test cells can be of the permanent or mobile type. First degree facilities generally utilize the permanent, concrete test cells.

Repair System Operation. The demand placed on the repair facility comes from two sources: unscheduled engine removals and scheduled engine removals. Unscheduled removals, also referred to as premature failures, are those engines which are removed from the aircraft prior to the scheduled removal point as a result of some type of failure. Typical failures which drive the unscheduled removal problem on the J-52 include oil leaks, compressor stalls, internal component failures, FOD (Foreign Object Damage), vibrations, gearbox failures, and metal contamination. In fact, a recent report issued by the Commander, Naval Air Force, Atlantic Fleet, (COMNAVAIRLAT), stated that over 60% of all non-FOD related J-52 removals in FY-83/84 were due to some type of premature failure.

Scheduled engine removals are those engines removed from the aircraft after reaching a specified number of operating hours for the purpose of undergoing a Hot Section Inspection (HSI). In a Hot Section Inspection, certain critical components in the combustion chamber and exhaust section are inspected for damage and repaired or replaced as necessary. HSI's are scheduled to occur every 750 operating hours. As indicated previously, less than 40% of the J-52's in service in FY 83/84 reached this point without some type of premature failure.

Having been removed from the aircraft, the engine is transported to the Supply Support Center (SSC) for turn-in. Upon completion of the necessary documentation, SSC coordinates the induction of the retrograde engine into the IMA for repair. It should be noted here that this coordination step does not always result in the induction of an engine into a "local" IMA. For bases with second or third degree facilities, the engine will require transportation to a facility with higher level repair capability if the extent of repair is determined to be beyond the capability of the local IMA.

Upon arrival at the repair facility, the engine undergoes administrative processing. This includes not only preparing the necessary paperwork for control of the repair process, but also a logbook screening process. The engine logbook is a binder which contains historical information pertaining to the engine's operating history and physical configuration. The purpose of the screening process is to identify any additional discrepancies which can be resolved during the repair, as well as to identify those engine components which are near their high-time removal point.

The objective of the logbook screening process (at a first degree site) is to decide whether to repair the engine locally or forward it to a depot facility for in-depth repair. This decision is largely subjective and is generally based on factors such as the number of available operating hours remaining to the HSI, the number of components within their high-time removal envolope, and/or the possible requirement for an Engineering Investigation (EI). Also, in some cases, upper echelon management will intervene and direct the flow of engines for repair at certain facilities to balance the workload.

Upon completion of the logbook screening process, the engine normally undergoes a pre-induction test cell run. This is a further attempt to identify discrepancies which can be reapired while at the IMA. A test cell crew is assigned to the task and prepares the engine for the test cell run. This involves the installation of certain equipment on the engine in order to facilitate controlling the engine during the run as well as monitoring engine performance.

Once the test cell run is complete, supervisory and management personnel review the engine's performance, and a determination is made as to the extent of the repair that is necessary. A minor repair is one which can be performed without a complete teardown of the engine. Normally, this could include removal and replacement of certain externally mounted components or, perhaps, some minor adjustment. For such repairs, QEC component removal is not required.

A major repair is one which requires a substantial degree of teardown to gain access to the affected area. For this type repair, a QEC crew places the engine on a QEC workstand and removes all QEC components. These components are tagged and identified by serial number and engine number to ensure no mismatch occurs between components, engines, and logbooks.

Having completed QEC removal (if required), the engine transitions into the repair phase. At this point, a repair crew and repair workstand is assigned. Conceivably, some repair sites may have crews designated to work on specific models only. There may be, for example, crews designated as J-52-P-6/8 repair crews or J-52-P-408 repair crews. Nevertheless, a crew is assigned, as well as a workstand.

During the entire repair phase (whether minor or major), delays can occur which result in work stoppage. Delays may occur while awaiting parts (AWP) or while awaiting maintenance (AWM). AWP time is self-explanatory. AWM time can occur for a number of reasons. For example, if a special tool used in de-coupling the turbine from the compressor breaks and requires repair before the job can continue, the delay encountered while repairing the tool is counted as awaiting maintenance (AWM). In general, whether minor or major repair, the processes include the initial stage of repair (including teardown), delays incurred for parts or other reasons, and the continuance and completion of repair (including build-up). The average time associated with each of these may differ significantly.

Next, a determination is made as to whether the completed engine requires a post-maintenance test cell run to verify the successful accomplishment of repairs. In general, this is a routine step, and relatively few engines are returned to use without a test cell run. Again, the test cell crew prepares the engine as before and conducts the run. Some possibility does exist that an engine may be declared unserviceable as a result of its test cell performance. If so, the lingering discrepancy is reviewed, and appropriate actions are taken to re-induct the engine for more repair.

Finally, after an engine has been declared fixed, preparations are made to release the engine back to the Supply Support Center (SSC). For major repairs, this includes the re-installation of QEC components which were removed originally. A QEC crew places the engine on a QEC workstand and performs the necessary QEC build-up. The engine is then delivered back to the SSC as an RFI (Ready for Issue) engine.

Model Construction

This section describes the construction of the Q-GERT network simulation model shown in Figure 4. As stated earlier, subtle differences occur in the composition and operation at different facilities. Therefore, a "typical" scenario of the system modeled in this project is provided first. Following this, the network logic and symbology are described.

Model Scenario. The hypothetical repair system modeled in this project operates continuously, 24 hours a day. It provides repair services for all three models of the J-52: the P-6, P-8, and P-408. No distinction is made between engines received from remote bases and those received from local operating units. However, a distinction is made between unscheduled removals and scheduled removals since different demand rates are imposed by each.

The interarrival rate of engines at the repair facility is exponentially distributed, with a mean of 36 clock hours between unscheduled removals, and 68 clock hours between scheduled removals. This is based on a forecast of 445,000 flight hours to be flown by all J-52's in a given year, 1300 engines in operation, approximately 260 days of operation per year, and 200 engines supported by the facility. In addition, the distinction between the two interarrival rates comes from the fact that unscheduled removals occur, on the average, at the 400th flight hour, and scheduled removals occur at the 750th flight hour point.

The crews performing maintenance on the engine fall into one of four categories: test cell crew, QEC crew, P-6/8 repair crew, and P-408 repair crew. The assumption is made that P-6's and P-8's are similar enough that the same crew can work on both types. The P-408, however, is significantly advanced in design and warrants more skilled crews. The facility modeled in this project has two QEC crews, two test cell crews, ten P-6/8 repair crews, and two P-408 repair crews. (Some facilities have chosen not to have separate crews for QEC removal and installation).

The repair facility has separate workstands designated for either QEC or repair. Four QEC workstands are available, and sixteen repair workstands are available. In addition, the facility has two permanent test cells.

Model Description. As transactions flow through the network of Figure 4, five attributes are assigned to the transactions to identify distinct characteristics. These attributes allow the modeler to attach identifying characteristics to each individual transaction flowing through the network. The table which follows describes the attributes used in this model and the values possible for each attribute. The information provided by these attributes is useful in making branching decisions as will be seen later in the model.

Attribute	Description	Value
1	Engine model	6 (for P-6) 8 (for P-8) 408 (for P-408)
2	Type of removal	1 (unscheduled) 2 (scheduled)
3	Extent of repair	1 (for minor) 2 (for major)
4	Repair capability	1 (local IMA) 2 (Depot)
5	Engine status	1 (Non-RFI) 2 (RFI)

The resources mentioned earlier (crews, workstands, and test cells) must also be tracked by the model. Resources are limited, and the "pace" of the maintenance effort is constrained by the availability of these resources. For this reason, resource numbers are assigned. The table which follows shows the resources employed in this model.

Resource #	Description	Units Available
1	QEC crew	2
2	Test cell crew	2
3	P-6/8 repair crew	10
4	P-408 repair crew	2
5	QEC workstand	4
6	Repair workstand	16
7	Test cell	2

Referring back to Figure 4, the demands upon the repair system are generated at nodes 1 and 2. Node 1 generates unscheduled removals, and node 2 generates scheduled removals. Attributes 2 and 5 are assigned the appropriate values to identify the type of removal scheduled or unscheduled) and the engine status, respectively.

Branching from node 3 and from node 4 establishes the percentage of incoming engines that are P-6, P-8, or P-408. Accordingly, nodes 5, 6, and 7 assign the appropriate engine model identifier to attribute 1. The branches from nodes 5, 6, and 7 to node 9 represent the transit time to the Supply Support Center. Here, the engine may incur some delay, but is eventually transported to the IMA facility.

Node 10 is the receival point at the IMA. Waiting occurs here while the engine undergoes administrative processing, represented by activity 7. From node 11, the engine takes one of two paths: to depot or to the IMA. Approximately 5% will require depot level maintenance which is performed at nodes 12 and 13. The remaining 95% are inducted for repair at the IMA.

From node 14, 97% of the engines will require a pre-induction test cell run. Nodes 15 through 23 represent this activity. A test cell crew is assigned at node 16, the engine is prepared for the test cell at activity 10, a test cell is assigned at node 19, and finally, activity 11 is the actual test cell run. Nodes 22 and 23 represent, respectively, the release of the test cell crew and the test cell upon completion of the run. These resources are then available for re-assignment.

From node 24, 95% of the engines are categorized as major repair, 5% as minor repair. If the repair is major, nodes 25 through 33 are encountered which represent the removal of the QEC components. A QEC crew is assigned at node 27 and a QEC workstand at node 29. Activity 12 is the removal of the QEC components. Upon completion of the job, the QEC crew and QEC workstand are freed up by nodes 32 and 33, respectively. If the repair is categorized as minor, activity 36 is encountered, signifying that QEC removal is not required.

Regardless of the path taken from node 24, the appropriate extent-of-repair designator is assigned to attribute 3 at node 25 or node 26.

Node 34 marks the beginning of the actual repair phase for the engine. The conditional branching from this node accounts for the different engine models. If attribute 1 (engine model) is 6 or 8, then the transaction follows activity 37 or 38 to node 35 where it waits for the assignment of a P-6/8 repair crew by node 36. Similar reasoning is applied to activity 39 as well for the P-408. In both cases, waiting may then occur at node 39 until a workstand is assigned at node 40.

The conditional branching from node 41 to node 42 represents the initial stages of repair in accordance with the extent-of-repair attribute. Major repairs incur a time associated with activity 13, while minor repairs incur a time associated with activity 14.

Next, probabilistic branching from node 42 occurs in accordance with the probabilities associated with experiencing delays. These may be due to AWP (activity 40) or AWM (activity 41). It may also be possible to experience no delay (activity 42). The duration of a time delay depends upon the extent of repair. Major repairs experience a much longer delay than minor repairs. Accordingly, the branching at node 44 checks the extent-of-repair attribute and routes the transaction along the appropriate branch. A similar logic is applied at node 54 for AWM.

If a delay is experienced (either AWP or AWM), a duplicate transaction is sent to node 50. At this point, a check is made to determine the engine model as indicated by the conditional branching from node 50. If the engine is a P-6 or P-8, then the repair crew is freed up by node 51 and made available for reassignment at the nodes indicated in the box below node 51. Similarly, node 52 releases the P-408 repair crew. This entire portion of the network is employed to simulate the fact that repair crews do not remain idle the entire time the engine is experiencing AWP or AWM delays.

Upon expiration of the delay, the engine is ready to resume its repair phase. Nodes 45 (for expiration of AWP) and 55 (for expiration of AWM) provide conditional branching once again to determine the engine model. This step is necessary in order to re-allocate the proper repair crew to the engine. For engines coming out of AWP status, node 47 assigns a P-6/8 repair crew, or node 49 assigns a P-408 repair crew, whichever is appropriate. A similar resource allocation scheme takes place at nodes 57 and 59 for engines coming out of AWM status.

The branching from node 60 to 61, and from 61 to 62 represents the completion of repair and build-up phase for engines in a major repair status. Activity 21 from node 60 to 62 represents the completion of repair for engines in a minor repair status. Having completed repair, the repair crews are then released. From node 62, a check is made to determine the engine model by examining attribute 1. If the engine is a P-6 or P-8, node 63 releases that type of repair crew and makes them available for re-allocation at the nodes in the box below node 63. Node 64 releases a P-408 repair crew in a similar manner.

Having completed the repair phase, 95% of the engines require a post-maintenance test cell run as indicated by the branch emanating from node 66 labeled as activity 55. Nodes 67 through 75 represent this activity. A test cell crew is allocated at node 68, the engine is prepared for the test cell in activity 22, a test cell is allocated at node 71, and the test cell run is made at activity 23. As with all other processes, the resources are freed up at the completion of the task. Node 74 releases the test cell crew, and node 75 releases the test cell. Both of these resources are made available for reassignment at the nodes indicated in the box below the free nodes.

Approximately 5% of the engines coming off the test cell have lingering discrepancies and require further maintenance. If so, these transactions are routed to node 85. Of these, 95% are designated as minor repair and 5% as major repair (attribute 3). The transaction is routed back to node 34 where it re-enters the repair process.

Transactions along activity 58 from node 75 to 89 represent engines with a successful test cell run. Conditional branching at node 89 checks to see if the repair was a major or minor repair. If it was major, the branch to node 76 is taken. Nodes 76 through 83 represent the QEC build-up phase. (Recall that only major repairs had the QEC components removed). Nodes 82 and 83 release the QEC crew and QEC workstand, respectively.

Finally, the engine is ready to be released back to the Supply Support Center for subsequent issue to fill a demand as required. Nodes 81 and 90 both designate the engine as RFI (Ready For Issue) by assigning a value of 2 to attribute 5. Activity 25 from node 83 to 84 and activity 63 from node 90 to 84, both represent the time in transit back to the SSC. At node 84 the transaction departs the system signifying the completion of the pipeline.

Care was taken in the development of the model to ensure that repair processes associated with minor and major repair were distinguished since their corresponding times are significantly different. Table I on the following page provides a listing of <u>all</u> activities identified in the model along with the statistical distribution employed, and estimates of the mean, minimum, maximum, and standard deviation values of each activity.

This completes the general description of the network model of the J-52 intermediate level repair system. Before concluding the discussion, however, some minor points about the model are discussed in order to clarify certain aspects of the symbology employed.

Table I

Activity Times (in hours)

Activity	Statistical Distribution	Mean	Min.	Max.	Dev.
Interarrival rate (unsched. removals)	Exponential	36.0	0.0	120.0	—
Interarrival rate (sched. removals)	Exponential	68.0	0.0	240.0	—
Transit to SSC	Lognormal	60.0	0.0	240.0	20.0
Transit to IMA	Normal	2.0	1.0	3.0	0.5
Admin. processing	Normal	48.0	10.0	72.0	12.0
Transit to depot	Normal	120.0	48.0	240.0	24.0
Repair at depot	Lognormal	456.0	288.0	624.0	60.0
Prepare engine for pre-induction test cell run	Lognormal	3.0	1.0	6.0	1.0
Perform pre-induction test cell run	Lognormal	4.0	2.0	16.0	0.5
QEC removal	Normal	3.0	2.0	5.0	0.5
Teardown (major repair)	Lognormal	48.0	36.0	96.0	6.0
Initial stage of minor repair	Lognormal	12.0	2.0	36.0	6.0
AWP for major repair	Lognormal	360.0	0.0	3168.0	48.0
AWP for minor repair	Lognormal	24.0	0.0	48.0	6.0
AWM for major repair	Lognormal	48.0	0.0	96.0	12.0
AWM for minor repair	Lognormal	12.0	0.0	36.0	6.0
Repair phase of major repair	Lognormal	168.0	48.0	336.0	48.0
Build-up phase of major repair	Lognormal	240.0	144.0	360.0	48.0
Completion of minor repair	Lognormal	24.0	6.0	48.0	8.0
Prepare engine for post-maint. test cell run	Lognormal	3.0	1.0	6.0	1.0
Perform post-maint. test cell run	Lognormal	4.0	2.0	16.0	0.5
QEC build-up	Normal	8.0	4.0	16.0	1.0
Transit back to user	Normal	60.0	0.0	240.0	20.0

Note that queue capacities are treated as infinite on all queues in the network. This implies that ample "waiting" space is available for engines in each stage of the pipeline, and that the repair process is not halted for lack of waiting room. In other words, there is always ample space for engines to accumulate at any particular point in the cycle.

In reality, this feature may not always be a feasible assumption. Floorspace limitations and building designs may place constraints on the ability to accumulate engines at some facilities. Generally, waiting space for engine accumulations at shore-based facilities does not present a problem. Waiting space at carrier-based facilities, however, presents a problem of some magnitude and must be considered carefully.

In such cases, the modeler may want to include blocking symbols on the network as a means of dealing with this constraint. (Blocking is explained in Appendix H). Using this feature enables the modeler to "halt the action upstream" should a transaction attempt to join a queue which is already full. When space opens up in the queue, Q-GERT automatically resumes the activity and allows the transaction to join the queue.

Note also that interval statistics nodes are present throughout the network. These were incorporated to demonstrate the ease with which incremental pipeline times can be determined. The time an engine enters the pipeline is established at the source nodes (nodes 1 and 2), and is tracked on each transaction throughout its trek in the pipeline. Statistics nodes can be inserted at almost any point in the network where it is desired to obtain a time reading.

The tracking of time on each transaction is also significant. It should be pointed out here that the model is constructed so as to allow 1000 hours of "simulated time" to pass before statistics are collected. This was an arbitrary choice of "warm-up" time for allowing the system to reach a fairly steady state operation before collecting statistics. In other words, the queues (the entire system for that matter) are empty at the start of the run, and the 1000 hours of initial warm-up time allow the system to become filled with transactions at a level approximating steady state in order to improve the accuracy of the statistics collected.

All information contained on the model in Figure 4 has been converted to computer input code which is acceptable to the Q-GERT Analysis Program. The Q-GERT Analysis Program is the software which is responsible for translating the input code into computer understandable language and performing the simulation. Appendix I contains the input code for the model constructed in this project.

V. Conclusion

Chapter Overview

The simulation model developed in Chapter IV (Figure 4) represents the culmination of the research effort of this thesis project. This chapter now takes a macro view of the model and analyzes some of its characteristics. First, a general discussion on the results of the model development is presented. In this section, the output results from an actual computer run of the model are described, as well as some inherent shortcomings and limitations of the model. Second, its use as a management tool is discussed in light of the research problem. Finally, some recommendations for follow-on research in this area are discussed.

Results of the Model Devolopment

The development of the model in Figure 4 is certainly a major step closer to investigating pipeline delays and backlog problems in the Navy's J-52 repair system. However, management is primarily interested in output results as an aid to decision making. For this reason, a discussion of the results of the development effort is presented in this section.

Output of the Model. Recall that not only was the graphical Q-GERT model presented in Chapter IV, but also the corresponding computer source code was provided in Appendix I. Furthermore, this source code was centered around the hypothetical scenario described in Chapter IV. The reason for including this source code was to be able to actually test the model and verify its operation. This is not to be confused with validation of the model, but simply an effort to "de-bug" or verify the operation of the model, and to demonstrate an interpretation of the output.

The source code was, in fact, verified on the Cyber computer at Aeronautical Systems Division at Wright-Patterson Air Force Base in Dayton, Ohio. The output data from the computer run is discussed in this section in order to acquaint the reader with how to interpret the results, as well as the usefulness of the model. In view of the size of the printout and the "readability" of the type, the printout was unsuitable for reproduction and inclusion in this report. However, essential data was extracted from the printout and put in tabular form in order for the reader to view the results. Tables II through VI at the end of this chapter contain this essential data from the printout.

The first table of output information provided by the Q-GERT Analysis Program relates to the average amount of time transactions took to reach certain nodes. In terms of the J-52 repair system, these node statistics refer to the average amount of time J-52 engines took to reach various points in the repair cycle pipeline. Table II shows a summary of the results, with the nodes listed sequentially.

Referring to Table II, for example, the average amount of time an engine spends in the complete pipeline is found at node 84. At this node it can be seen that the average pipeline time over the course of the simulation was approximately 2644 hours, or 110 workdays. The two columns on the far right side reveal that the minimum amount of time observed by an engine in the complete pipeline was about 2341 hours, or 97 workdays, while the maximum pipeline time was observed to be about 2913 hours, or 121 workdays.

The average time spent in any given portion of the pipeline can also be found by subtracting the smaller value from the larger value between two nodes since the nodes are listed sequentially and all times start at the same point. For example, an estimate of the average amount of time an engine undergoing major repair spends in the actual repair phase (excluding test cell runs and QEC work) can be found by subtracting the node 31 average time from the node 69 average time. The result is approximately 2217 hours, or 92 workdays, and includes delays associated with waiting for crew and workstand assignments, as well as AWP and AWM time.

Tables III and IV would be perhaps the most useful to managers interested in delays and backlogs in the pipeline. These two tables contain information on Q-nodes which is where waiting occurs in the network. Referring to Table III, it can be seen that the average amount of waiting time experienced at each queue in the system can be determined. At Q-node 35, for example, approximately 1719 hours of delay is incurred by the P-6's and P-8's awaiting repair crew assignment and workstand assignment. Additionally, at one point in the simulation, a maximum of 133 engines were observed to be waiting at this queue. Table IV shows that the average number of engines waiting at Q-node 35 was about 58. Although these figures are highly unrealistic, it must be remembered that the results are based on contrived parameters and a hypothetical scenario. They are included here to illustrate the type of information available to managers dealing with limited resources.

Tables V and VI provide information on resources employed in the simulation (crews, workstands, test cells). These tables are actually compliments of each other since one gives information on the average number of units of a certain resource employed (utilization), while the other gives information on the average number of resource units uncommitted or unassigned (availability).

Referring to Table V it can be seen that the average number of units of resource #2 utilized was approximately 0.39, with an average availability of approximately 1.60 from Table VI. In other words, at least one test cell crew was idle over 80% of the time.

Similarly, out of the 10 available P-6,8 repair crews (resource #3), Table V shows that the average number of crews utilized continuously was 10, with an average availability of 0.0 from Table VI. In other words, the results clearly indicate that P-6 and P-8 repair crews are continously employed, represeting a potentially scarce resource.

Shortcomings of the Model. One of the goals of simulation modelers is to replicate as closely as possible the real system to avoid losing too much accuracy. The near impossibility of reaching a 100% correspondence with the real system gives rise to shortcomings and limitations with which the modeler must contend. A few of the shortcomings of this model are discussed here.

The J-52 repair cycle is a complex system to model. To do greater justice to the system, more nodes and branches are needed to account for additional on-going activities not included in this model. The level of detail presented in this model, however, was constrained by the limitations of the Q-GERT Analysis Program, which places an upper limit of 100 on the maximum number of nodes which may be placed in the network. Although it has not been confirmed, the author understands that larger versions of the Q-GERT Analysis Program may be available which can accomodate a significantly greater number of nodes in the network. If this larger version of Q-GERT does, in fact, exists, its use should be investigated.

To simplify construction of the model and to present the model only as a concept to spark further work, certain assumptions were made regarding Q-node conditions that represent shortcomings inherent in the model. Queues represent waiting areas, and waiting areas do not always enjoy the luxury of having an infinite amount of space. Nevertheless, infinite queue capacities were specified on all Q-nodes.

To restrict queue capacities would require extra consideration to be given to the possibility of transactions arriving at a queue which is full. If not dealt with properly, this situation can result in transactions "disappearing" from the system. Blocking or balking are two possibilities for coping with this problem. However, in this particular model, the network maximum nodal limitations would have been exceeded.

The final limitation discussed here relates also to Q-nodes. At the start-up of the system, it is desirable to have transactions already in the system to represent the system at steady state operation. Failure to do so implies that the system must "start from scratch" and feed transactions into the system for a certain period of time before it reaches a relatively steady state.

The model in this project did not incorporate initial transactions in the queues because of problems encountered with attribute assignments for conditional branching. On a trial run, transactions were placed in all queues initially. As the simulation progressed, it was noted that these transactions never left the queues because they had no attribute values assigned to accomodate conditional branching. Thus the simulation was halted by these "stalled" transactions.

Two methods for overcoming this are the use of FORTRAN inserts and the provision of a "warm-up" time. FORTRAN inserts are discussed by Pritsker (31:235-296) and are a means of using sub-routines to accomplish this task. To avoid additional complexity, however, the latter approach was taken which, according to the output data, came very near to replicating steady state conditions. A 1000 hour warm-up period was used to achieve steady state conditions before collecting statistics.

The Model as a Management Tool

As stated in Chapter I, the original purpose in the development of this model was to offer an approach to examining pipeline problems in the Navy's J-52 repair system. It does not specifically address any particular issue but offers management an approach to investigating two key issues - pipeline backlogs and resource utilization. With a fair amount of creativity, managers can experiment with a number of repair system design structures or resource utilization schemes in order to help pinpoint different ways of making the system operate more efficiently and more effectively.

Repair site consolidation was mentioned in Chapter I as one approach the Navy is considering as a solution to some of the pipeline problems it is experiencing. The validity of this approach has not been established, nor is it within the scope of this report to offer a judgement on it. Given, however, that consolidation of facilities is pursued by the Navy, it will become necessary to establish some criterion by which management will decide which facilities are candidates for consolidation. The contention of the author is that the Q-GERT simulation model may be helpful in this area. If the established criterion relates to backlog delays or resource utilization, then the model could be used to compare the operation of like facilities and to determine, perhaps, the most (or least) efficient or effective facility among those compared. Such a comparison may assist management in deciding upon a consolidation plan.

Minimizing flow time through the pipeline can also be achieved by optimizing the number of resources at each facility. By using the model output, management can identify those resources with a high percentage of idle time. These resources then could possibly be reallocated to other facilities where the same resource is scarce.

Recommendations for Further Research

Simulation models, by their very nature, are approximations of real world systems. Because of this, there is always room for improvement in the model to achieve greater accuracy. This section provides a short discussion on areas recommended for follow-on research in order to expand the usefulness of the model.

Various Q-GERT network designs should be tested. The Q-GERT model in this project is not the only alternative for investigating the J-52 repair system, only the first attempt. Other arrangements of the network should be tested to attempt a more efficient design. Care should be exercised, however, to insure that modifications to the model do not simply add to its complexity without a significant increase in accuracy.

Probably the most important step to be undertaken next, however, is validation of the model. This step requires an extensive statistical analysis of the parameters in the network in order to obtain the correct statistical distributions for the various processes taking place. The goal is to achieve output results similar to actual performance of the real world system. Follow-on researchers should not attempt any comparison of facilities for the purpose of measuring efficiency or effectiveness until a validation has been accomplished. This will be achieved only after giving careful attention to using statistically sound parameters.

Having validated the model, follow-on researchers should attempt to establish confidence intervals for the output parameters estimated by the simulation. A basic limitation in the use of simulation is the inability to achieve exact answers. This is not always a disadvantage and often provides satisfactory answers with reasonable speed and effort. Often, however, it is desirable to achieve a certain degree of accuracy in the mean values of the output parameters. Statistically, the greater the number of runs of the model, the higher the accuracy or degree of confidence. Thus, it remains for follow-on researchers to establish a desired degree of confidence, and then to determine the number of simulation runs needed to achieve that level of confidence.

Having a validated model to work with and an established confidence interval, other investigators should conduct research to examine the model's performance under different environmental conditions. A great deal of emphasis by top defense management personnel has been placed on this country's ability to mobilize its defense resources in a national emergency or an international crisis. Modifying the simulation model to replicate the jet engine repair cycle in a wartime environment would provide beneficial information.

The repair cycle and jet engine logistics support aboard aircraft carriers also represent unique logistics problems not found elsewhere. The entire logistics chain which feeds serviceable engines to aircraft carriers at great distances cannot afford delays or bottlenecks in emergency situations. Thus, all resources involved in moving engines through this chain must operate as efficiently and effectively as possible. A Q-GERT network model offers an excellent "first step" in examining such a pipeline.

Table II

Average Node Statistics (in hours)

Node	Average	Std. Deviation	Std. Deviation of Average	Minimum	Maximum
8	60.4622	0.9344	0.2955	58.2142	61.2006
11	394.6642	121.0296	38.2729	187.1995	581.9091
12	502.3682	139.4191	44.0882	308.3892	716.4286
13	940.2804	137.4196	43.4559	730.4155	1149.4733
17	394.6205	120.1126	37.9829	186.1631	579.0867
20	397.6299	120.0594	37.9661	189.4924	582.1599
21	401.4875	119.9208	37.9223	193.4860	586.1801
30	401.1637	119.6260	37.8290	193.9953	587.3556
31	404.1086	119.6627	37.8407	196.9910	590.3745
88	2277.4214	144.0010	45.5371	2021.3996	2503.5563
69	2621.1227	158.0313	49.9739	2408.7907	2888.8763
72	2624.1127	157.9992	49.9637	2411.9531	2891.7288
73	2621.9671	159.7578	50.5199	2415.9438	2895.6755
80	2602.6165	161.0411	50.9257	2378.1947	2906.5019
81	2609.4817	159.9619	50.5844	2386.1645	2914.4771
84	2644.0943	166.5269	52.6604	2341.7039	2913.2877

Table III

Average Waiting Time (in hours)

Node	Average	Std. Deviation	Std. Deviation of Average	Max. Number in Q-Node
9	0.0980	0.0269	0.0085	2
10	278.6157	118.1905	37.3751	36
15	0.0596	0.0290	0.0092	2
18	0.0000	0.0000	0.0000	0
25	0.0130	0.0115	0.0036	2
28	0.0000	0.0000	0.0000	0
35	1719.5239	138.6097	43.8332	133
37	1906.7150	216.6913	68.5238	45
39	189.3763	14.8620	4.6998	8
46	54.9930	12.7174	4.0216	8
48	290.1234	93.7718	29.6532	6
56	126.8985	89.2496	28.2232	3
58	294.2421	357.6970	113.1137	2
67	0.1494	0.0604	0.0191	2
70	0.0000	0.0000	0.0000	0
76	0.0158	0.0151	0.0048	1
78	0.0000	0.0000	0.0000	0

Table IV

Average Number in Q-Node

Node	Average	Std. Deviation	Std. Deviation of Average	Minimum	Maximum
9	0.0042	0.0012	0.0004	0.0020	0.0062
10	12.4644	5.5960	1.7696	2.9908	21.1748
15	0.0023	0.0011	0.0004	0.0014	0.0052
18	0.0000	0.0000	0.0000	0.0000	0.0000
25	0.0005	0.0004	0.0001	0.0000	0.0011
28	0.0000	0.0000	0.0000	0.0000	0.0000
35	58.1768	6.2765	1.9848	50.8551	72.2064
37	16.2272	2.9021	0.9177	11.2782	19.5791
39	3.7825	0.2335	0.0738	3.5404	4.3078
46	0.8022	0.2146	0.0678	0.5661	1.2307
48	0.9543	0.3248	0.1027	0.5460	1.4859
56	0.1219	0.0950	0.0300	0.0146	0.2994
58	0.0654	0.0672	0.0212	0.0000	0.1470
67	0.0028	0.0011	0.0003	0.0014	0.0048
70	0.0000	0.0000	0.0000	0.0000	0.0000
76	0.0003	0.0003	0.0001	0.0000	0.0006
78	0.0000	0.0000	0.0000	0.0000	0.0000

Table V

Average Resource Utilization

Resource Number	Avg.	Std. Deviation	Std. Deviation of Average	Min.	Max.	Max. # Utilized
1/QEC Crew	0.2475	0.0063	0.0020	0.2347	0.2557	2
2/TS Crew	0.3958	0.0042	0.0013	0.3903	0.4046	2
3/P-6,8 Crew	10.0000	0.0000	0.0000	10.0000	10.0000	10
4/P-408 Crew	2.0000	0.0000	0.0000	2.0000	2.0000	2
5/QEC W/S	0.2475	0.0063	0.0020	0.2347	0.2557	3
6/Repair W/S	15.9940	0.0077	0.0024	15.9758	16.0000	16
7/Test Cell	0.2267	0.0030	0.0009	0.2223	0.2330	2

Table VI

Average Resource Availability

Resource Number	Avg.	Std. Deviation	Std. Deviation of Average	Min.	Max.	Max. # Available
1/QEC Crew	1.7525	0.0063	0.0020	1.7443	1.7653	2
2/TS Crew	1.6042	0.0042	0.0013	1.5954	1.6097	2
3/P-6,8 Crew	0.0000	0.0000	0.0000	0.0000	0.0000	0
4/P-408 Crew	0.0000	0.0000	0.0000	0.0000	0.0000	0
5/QEC W/S	3.7525	0.0063	0.0020	3.7443	3.7653	4
6/Repair W/S	0.0060	0.0077	0.0024	0.0000	0.0242	1
7/Test Cell	1.7733	0.0030	0.0009	1.7670	1.7777	2

Appendix A: Squadron Homebase Locations for the J-52

(Source: 9; 28)

Activity	Location
VA - 34	NAS Oceana, Va.
VA - 35	NAS Oceana, Va.
VA - 42	NAS Oceana, Va.
VA - 45	NAS Key West, Fl.
VA - 52	NAS Whidbey Island, Washington
VA - 65	NAS Oceana, Va.
VA - 75	NAS Oceana, Va.
VA - 85	NAS Oceana, Va.
VA - 95	NAS Whidbey Island, Washington
VA - 115	NAS Whidbey Island, Washington
VA - 127	NAS Lemoore, Calif.
VA - 128	NAS Whidbey Island, Washington
VA - 145	NAS Whidbey Island, Washington
VA - 165	NAS Whidbey Island, Washington
VA - 176	NAS Oceana, Va.
VA - 196	NAS Whidbey Island, Washington
VAK - 208	NAS Alameda, Calif.
VAK - 308	NAS Alameda, Calif.
VAQ - 33	NAS Norfolk, Va.
VAQ - 129	NAS Whidbey Island, Washington
VAQ - 130	NAS Whidbey Island, Washington
VAQ - 131	NAS Whidbey Island, Washington
VAQ - 132	NAS Whidbey Island, Washington
VAQ - 133	NAS Whidbey Island, Washington
VAQ - 134	NAS Whidbey Island, Washington
VAQ - 135	NAS Whidbey Island, Washington
VAQ - 136	NAS Whidbey Island, Washington
VAQ - 137	NAS Whidbey Island, Washington
VAQ - 138	NAS Whidbey Island, Washington
VAQ - 139	NAS Whidbey Island, Washington
VAQ - 209	NAS Norfolk, Va.
VAQ - 309	NAS Whidbey Island, Washington
VC - 1	NAS Barber's Point, Hi.
VC - 5	NAS Cubi Point, Pl.
VC - 8	NAS Roosevelt Roads, PR.
VC - 10	NAS Guantanamo Bay, Cuba
VC - 12	NAS Oceana, Va.
VC - 13	NAS Miramar, Calif.
VF - 43	NAS Oceana, Va.
VF - 126	NAS Miramar, Calif.

Squadron Homebase Locations for the J-52 (continued)

Activity	Location
VMAQ - 2	MCAS Cherry Point, N.C.
VMAQ - 4	NAS Whidbey Island, Washington
VMAT - 102	MCAS Yuma, Arizona
VMAT - 202	MCAS Cherry Point, N.C.
VMA - 121	MCAS El Toro, Calif.
VMA - 211	MCAS El Toro, Calif.
VMA - 214	MCAS El Toro, Calif.
VMA - 223	MCAS Cherry Point, N.C.
VMA - 224	MCAS Cherry Point, N.C.
VMA - 242	MCAS El Toro, Calif.
VMA - 311	MCAS El Toro, Calif.
VMA - 331	MCAS Cherry Point, N.C.
VMA - 332	MCAS Cherry Point, N.C.
VMA - 533	MCAS Cherry Point, N.C.
VT - 4	NAS Pensacola, Fl.
VT - 7	NAS Meridian, Miss.
VT - 21	NAS Kingsville, Texas
VT - 22	NAS Kingsville, Texas
VT - 24	NAS Chase Field, Texas
VT - 25	Nas Chase Field, Texas
VT - 86	NAS Pensacola, Fl.
VX - 4	NAS Point Mugu, Calif.
VX - 5	NAS China Lake, Calif.
H&MS - 32	MCAS Cherry Point, N.C.
H&MS - 13	MCAS El Toro, Calif.
H&MS - 10	MCAS Yuma, Arizona
H&MS - 12	Iwakuni, Japan
H&MS - 31	Beaufort, S.C.
H&MS - 24	Kaneohe, Hi.
H&MS - 14	MCAS Cherry Point, N.C.
Blue Angels	NAS Pensacola, Fl.
NAS Patuxent River	Patuxent River, Md.
Naval Weapons Center	China Lake, Calif.
NAS Point Mugu	Point Mugu, Calif.
Navy Fighter Weapons School	NAS Miramar, Calif.
Grumman Aerospace Corp.	New York

Appendix B: J—52 Repair Site Classifications and Locations

(Source: 9; 28)

Organizational and Third Degree Intermediate	Organizational, Third, and Second Degree Intermediate	Organizational, Third, Second, and First Degree Intermediate
NAS Roosevelt Roads, PR.	MCAS Yuma, Arizona	NAS Chase Field, Texas
NAS Dallas, Texas	NAS Guantanamo Bay	NAS Kingsville, Texas
NAS Alameda, Calif.	NAVPRO Bethpage, N.Y.	NAS Meridian, Miss.
NAS Cecil Field, Fl.	NWEF Kirkland AFB	NAS Oceana, Va.
NAS Memphis, Tenn.	NAS Key West, Fl.	NAS Miramar, Calif.
NAS Willow Grove, Pa.	NAS South Weymouth, N.H.	NAS Pensacola, Fl.
NAVPRO Long Beach, Ca.	H&MS - 24 Kaneohe, Hi.	NAS Cubi Point, Pl.
NAS Point Mugu, Calif.	H&MS - 31 Beaufort, S.C.	NAS Whidbey Island, Wash.
NAF Atsugi, Japan	H&MS - 12 Iwakuni, Japan	NAS Patuxent River, Md.
U.S.S. Carl Vinson	H&MS - 32 Cherry Pt. N.C.	H&MS - 42
U.S.S. Midway		H&MS - 13
U.S.S. Coral Sea		H&MS - 14
U.S.S. Eisenhower		
U.S.S. Forrestal		
U.S.S. Saratoga		
U.S.S. Ranger		
U.S.S. Independence		
U.S.S. Kitty Hawk		
U.S.S. Constellation		
U.S.S. America		
U.S.S. Kennedy		
U.S.S. Enterprise		
U.S.S. Nimitz		

Depot, First, Second, and Third Degree Intermediate

NARF Jacksonville, Fl

* NARF Alameda, Calif.

* J-52-P-8B only

Appendix C: J–52 IMA Engine Turnaround Time

(Source: 11)

Fiscal Year	Average No. of Pipeline Days
FY-79	38.0
FY-80	63.5
FY-81	82.7
FY-82	96.1
FY-83 *	> 130.0

* The figure shown for FY-83 was provided as an estimate (21; 38) since the actual figure was not available.

Appendix D: J–52 IMA Engine Awaiting Parts Time

(Source: 11)

Fiscal Year	Average No. of Days
FY-79	29.4
FY-80	50.4
FY-81	39.8
FY-82	48.2

Appendix E: J—52 IMA Engine Repairs Transferred to Another Site

(Source: 11)

The data below represents the number of engines (by facility) that were transferred to another site for the accomplishment of repairs which were within the original site's capability.

Repair Site	Degree Assigned	# Engines Transferred
NAS Alameda, Calif.	2	4
NAS South Weymouth, N.H.	2	2
NAS Willow Grove, Pa.	3	9
NAS Key West, Fl.	2	22
NAS Guantanamo Bay, Cuba	2	7
NAS Roosevelt Roads, PR.	3	2
U.S.S. Midway	3	15
U.S.S. Coral Sea	3	2
U.S.S. Forrestal	3	1
U.S.S. Ranger	3	8
U.S.S. Independence	3	3
U.S.S. Kitty Hawk	3	11
U.S.S. Constellation	3	13
U.S.S. Enterprise	3	1
U.S.S. America	3	11
U.S.S. Kennedy	3	5
U.S.S. Nimitz	3	4
U.S.S. Eisenhower	3	13
H&MS - 13	1	41
H&MS - 12	2	15
H&MS - 24	2	2
H&MS - 31	2	6
H&MS - 32	2	13
NAS Oceana, Va.	1	7
NAS Cecil Field, Fl.	3	1
NAS Kingsville, Texas	1	5
NAS Chase Field, Texas	2	18
NAS Cubi Point, Pl.	1	27
MCAS Yuma, Arizona	2	7
NAS Point Mugu, Calif.	2	15
NAS Pensacola, Fl.	1	1
		291

Appendix F: Phases in the Life Cycle of the J–52 Engine

(Source: 17)

From the standpoint of engine reliability, Figure 5 illustrates the theoretical relationship between engine operating time and failure rate, and is often referred to as the "bathtub curve." Superimposed on the graph are the three major phases in the life of the engine.

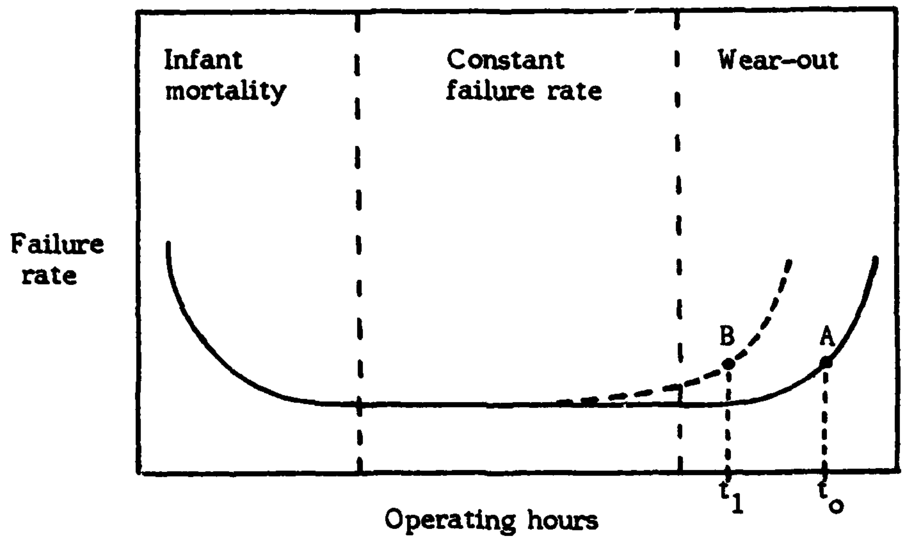

Figure 5. Typical Failure as a Function of Time (17:257–258)

Initial estimates by the Naval Engineering Support Office (NESO) in Jacksonville, Fl., indicated that the J-52-P-6B and the J-52 -P-8B would experience a failure rate corresponding to Point A at projected hours, t_o. However, revised estimates based on recent data suggest that this failure rate is occurring at time, t_1, which is earlier than anticipated (28). Point B reflects an early upswing of the curve and represents a more accurate estimate of the position of these two engine models in the "wearout" phase of the life cycle.

Maintenance and management malpractice were suggested as two of the reasons for this apparent shift of the curve to the left (28). It is believed that failure to take proper care of the engine has induced early wearout.

Appendix G: Background for the Development of a Computer Simulation Model

Introduction

This section presents a considerable amount of discussion on the background of modeling and simulation. The intent is not to begin a long journey on the road to the creation of a manuscript on the topic, but to highlight some basic concepts and features of simulation modeling. The assumption is made that not every reader is completely familiar with the topic, and that a brief background will provide a common referrence point for understanding the model development in Chapter IV. Although several citations are made, Morris (27) and Shannon (35) are the main sources of information for the material in this section.

Three objectives are met in this appendix. First, the concept of modeling in general is discussed. Morris (27:B707) and Shannon (35:ix) view this as an art in which intuition on the part of the modeler plays a key role.

Second, the topic of simulation as one form of modeling is discussed. Some of the basic principles or "building blocks" of simulation are presented, as well as some of the underlying assumptions and shortcomings with which managers must contend. The emphasis is not merely on explaining what has already been established, but on alerting managers to some hidden imperfections in simulation modeling so that they can use it with discretion and imagination.

Third, some specific network simulation models are discussed. Included in this section is a discussion on the broader topic of activity networks in general, as well as a specific family of network simulation languages, GERT (Graphical

Evaluation and Review Technique). Q-GERT (for Queueing systems), one of several members of the GERT family, is the simulation language chosen for this project. A brief introduction to some of the features and limitations of Q-GERT is also provided in this section. In Appendix H, the reader is introduced to some of the elementary, intermediate, and advanced concepts of Q-GERT to facilitate a better understanding of the model development in Chapter IV.

The Art of Modeling

As previously stated, the process of abstraction and translation of some management phenomenon into a scientific model (the modeling process) is probably best described as an art in the sense that it remains largely intuitive. Thus, any preconceived set of rules set forth for construction of models would have limited usefulness at best. Skill in modeling involves a sensitive and selective perception of management situations (27). One's ability to bring some sort of order out of what appears to be confusion determines to a great extent the degree to which models give structure to experience. Morris (27:B709) describes the art of modeling in terms of three hypotheses:

- The process of model development is a process of elaboration or enrichment in which simple models evolve into more elaborate models which more nearly reflect the management situation at hand.

- Analogy or association with previously well-developed models plays an important role in determining the starting point for the elaboration or enrichment process.

- The elaboration or enrichment process involves looping or alternation procedures

Morris (27:B711-B715) also offers seven suggestions for the experienced or inexperienced modeler to follow in constructing a model of a management problem:

1. Factor the system problem into simpler problems. The result is several problems whose solutions are sub-optimal or approximate from the total system viewpoint.

2. Establish a clear statement of the deductive objectives. This involves clear statements of the model's objectives such as the prediction of the consequences due to various policies or the suggestion of an optimal policy.

3. Seek analogies. Attempt to relate the problem at hand with some previously well-developed logical structure. This should be done early as an analogy may suggest a certain approach to the specific problem.

4. Consider a specific numerical instance of the problem. The specification of a simple instance of the problem often helps the modeler to identify necessary assumptions.

5. Establish some symbols. Choose symbols which are suggestive of their interpretation and give careful definition to each.

6. Write down the obvious. Identify simple laws, input-output relations, ideas expressed by assumptions, or consequences of simple, trivial problems.

7. Once a tractable model is obtained, enrich it. If it still remains cumbersome and overly complex, simplify it.

Models are developed to serve a multitude of quantitative and qualitative functions for managers. Beyond a rough description of a model as simple or complex, one must also consider certain characteristics:

- Relatedness. How many previously known results does the model bring to bear upon the problem?

- Transparency. How obvious is the interpretation of the model?

- Robustness. How sensitive is the model to changes in the assumptions which characterize it?

- Fertility. How rich is the variety of deductive consequences which the model produces?

- Ease of Enrichment. What difficulties are presented by attempts to enrich and elaborate the model in various directions?

Logistics models have gradually evolved over time but have been a key element in the planning and support of military operations since World War II. The number and complexity of weapon systems as well as the availability of modern technology have grown over this period of time. The result has been a significant change in the nature of warfare and the complexity of the requirements imposed on management. Accordingly, Drezner and Hillestad (12:1) state that logisticians will play an increasingly important role and will have to rely more and more on models to deal with the complexities of procuring, maintaining, and transporting military material, facilities, and personnel. Specific areas in which support modeling has been successfully applied include:

- Resource forecasting,
- Maintenance management policy-making including determination of inspection and replacement intervals, as well as workload scheduling,
- Maintenance facility location and layout, and
- Determination of training and manpower requirements for the maintenance of weapon systems.

The Simulation Process

Background. Simulation has its roots in the management science discipline. It is one of the most powerful analysis tools available to those responsible for the design, operation, and management of complex systems. Shannon (35:ix) comments that because it is so poorly understood, it is as much an art as a science and that no firm rules or fixed outlines are available to guide a systems analyst in model development. Simulation can enlighten or mislead a manager; this depends largely on the extent to which he is aware of certain implications of the model's assumptions, strengths and weaknesses, benefits and costs.

Management today is becoming increasingly difficult as the man-machine systems in our age of exploding technology become more complex. This complexity is the result of numerous interrelations among the various elements of the systems. The emergence of the Systems Age (36:5-35) gave birth to the science of systems analysis which requires that managers recognize the fact that changing one aspect of a system may very well produce changes or create the need for changes in other parts of the system. The systems analysis concept continues to evolve as managers and system designers refine their understanding of the ramifications of changes in a system.

Webster's Collegiate Dictionary defines simulation as follows: "to feign, to attain the essence of, without the reality." A number of authors have offered their own definitions of simulation but Shannon's seems to capture the basic idea in a simple statement:

> Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose of either understanding the behavior of the system, or evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system (35:2).

Thus, a simulation model of a real system is a representation of a group of objects or ideas in some form other than the actual entity itself. The model seeks to describe the behavior of the system, construct theories or hypotheses that account for this observed behavior, and make use of these theories or hypotheses to predict future behavior of the system as changes are made to system inputs or design.

Simulation as we know it today received its original impetus from aerospace programs (35:2). The literature today, however, is replete with countless books, technical articles, papers, reports, and theses on the subject of simulation, attesting to its widespread growth and impact in a number of fields. Simulation models serve a variety of functions (usually prediction and comparison) and come in many forms (mathematical models are most common). Network models using languages such as Q-GERT (Queueing-Graphical Evaluation and Review Technique) are highly beneficial in complex systems because they force the system investigators to "think through" the steps that are necessary in the proper sequence. Such a task helps to identify important interrelationships, needed accomplishments, timing of activities or processes, availability of critical resources, and many other important aspects which must make the system work.

Advantages and Disadvantages of Simulation. One of the dominant questions that any systems analyst should be concerned with from the very start of a project is, "When is simulation appropriate?" Although it is an extremely valuable and useful approach to problem solving, it is certainly not a panacea for all of management's problems. Nevertheless, despite its lack of mathematical sophistication and elegance, it enjoys status as one of the most widely used quantitative techniques employed in management problem solving. Tables VII and VIII illustrate the relative popularity and preference for simulation among practitioners and managers.

To address the question of simulation appropriateness, it is helpful first to consider the ideal approach to studying system behavior. Obviously, the greatest

Table VII

Utility of O.R. Techniques to Practitioners (35:12)

Topic	Value
Probability theory (and statistical inference)	0.182
Economic analysis (cost effectiveness)	0.150
Simulation	0.143
Linear programming	0.120
Inventory	0.097
Waiting line (queueing)	0.085
Network analysis (sequencing)	0.072
Replacement analysis	0.042
Gaming theory	0.040
Dynamic programming	0.031
Search techniques	0.020
Non-linear programming	0.018
	1.000

Table VIII

Quantitative Tools Most Frequently Employed in

Corporate Planning (35:13)

Topic	Frequency	%
Simulation studies	60	29
Linear programming	43	21
Network analysis (including PERT & CPM)	28	14
Inventory theory	24	12
Non-linear programming	16	8
Dynamic programming	8	4
Integer programming	7	3
Queueing theory	7	3
Other	12	6
	205	100

benefit would be achieved by performing direct manipulation of variables in the real life system itself to eliminate the difficulties in achieving a good match between the model and actual conditions. Barish (1:454-466), however, points out some obvious limitations to this approach:

- Disruption of operations,
- Possibility of observing the "Hawthorne effect",
- Often more time consuming and more costly than sampling,
- Precludes exploring many alternatives possible only through simulation, and
- Difficulty in maintaining stability in the operating conditions.

Recognizing the infeasibility of direct experimentation, the next step is to explore the limitations and potential usefulness of a simulation model of the real problem. Shannon (35:11) identifies six conditions which are favorable to its use:

1. A complete mathematical formulation of the problem cannot be developed, or the mathematical procedures are so complex and arduous that simulation provides a simpler method of solution.
2. Analytical solutions exist but are beyond the mathematical ability of available personnel.
3. It is desirous to observe a running history of the system's behavior rather than parameters at a single point in time.
4. Simulation may be the only possibility because of the difficulty of observing phenomena in their actual environment - e.g., space studies of vehicles in interplanetary flight.
5. Manipulation of time duration is possible for processes with extraordinarily long or short time frames. Simulation affords complete control over time, and a phenomenon may be speeded up or slowed down to enhance the investigation process.
6. Simulation serves as a powerful educational and training tool. The systems analyst can "play" with the system and gain a

better understanding of its workings as well as a better feel for the specific problem being addressed.

Similarly, there are times when simulation is not the most efficient and effective manner of achieving the desired results. These disadvantages include:

1. Model development is often time consuming, expensive and dependent upon talent that may not be readily available.
2. Many simulation models present a deceptive appearance of accurately reflecting the real world, and this often goes unnoticed by the systems analyst.
3. Simulation is imprecise; a sensitivity analysis only partially overcomes this difficulty.
4. The numerical results presented by a simulation model are often given much more validity than is justified.

The Stages of the Simulation Process. To augment this discusssion on the background of simulation modeling, the stages of the simulation process are presented (35:21-33). The entire process, beginning with the identification of a problem, is illustrated in the flowchart of Figure 6 and is described below.

Problem Identification and Formulation. Shannon (35:25) relates Albert Einstein's comment that "the proper formulation of a problem is even more essential than its solution." The initiation of a project begins when someone in the organization decides that a problem exists and needs investigation. Unfortunately, the communication of this problem by management is often vague and reflects a lack of certainty about the true nature of the problem. The systems analyst must, therefore, engage in a preliminary investigation and be able to articulate the problem (if it exists) in terms of deviations from the systems goals and objectives.

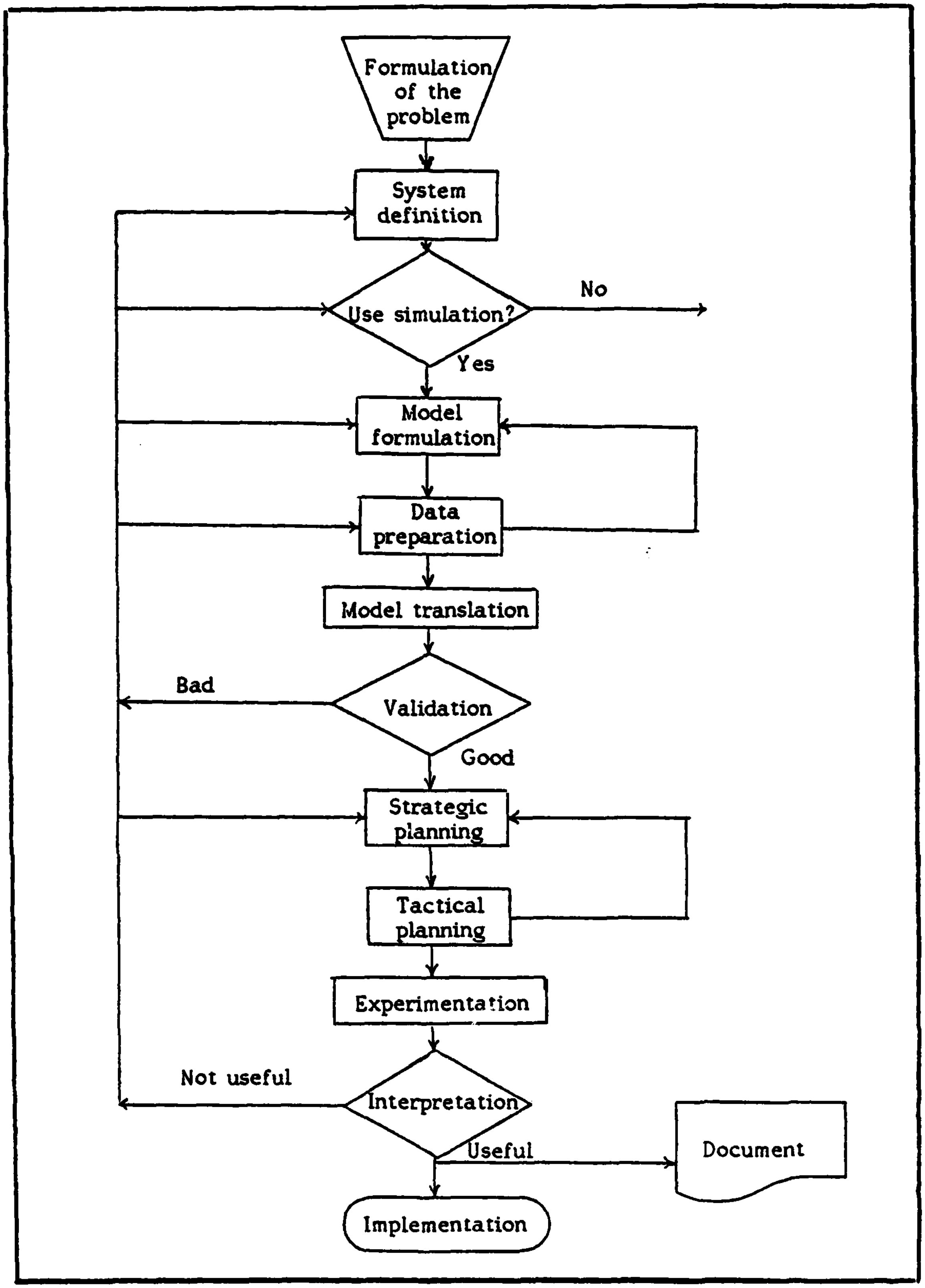

Figure 6. Flowchart of a simulation process (35:24)

System Definition. The system boundaries must be determined in addition to restrictions and measures of performance. This is an important step since all systems themselves are subsystems of other larger systems.

Model Definition and Formulation. The real system under investigation is reduced to a logical flowchart or a static model. The desire is to neither oversimplify to the point of becoming trivial (or worse, misleading), nor to carry it to so much detail that the model becomes clumsy or prohibitively expensive. In this stage a decision is made regarding the applicability of simulation to the problem. Assuming it applies, we proceed to the next step.

Data Gathering and Preparation. The data needed by the systems analyst must be identified and reduced to useable form. This includes both quantitative and qualitative data pertinent to the problem. Information about the inputs and outputs of the system, the various components of the system, and the interdependencies of these components must be specified. Given the availability of this information, the simulation model is then constructed.

Model Translation. In this stage the simulation model is described in a language acceptable to the computer to be used. A number of simulation languages are available such as PERT, SIMSCRIPT, SIMULA, DYNAMO, Q-GERT, and GPSS, all of which possess subtle differences. Unfortunately, the choice of language is often dictated by the type of machine available and the language known to the analyst.

Validation of the Model. In a broad sense, validation is the process of bringing to an acceptable level the user's confidence that any inference about the system derived from the simulation is correct. Shannon (35:29) comments that "there is no such thing as a test for validity" and that "it is impossible to prove that any simulator is a correct or true model of the real system." Three criteria may be used, however, to validate a model. First, it must be determined that the model has face validity. This can be done, for example, by comparing sets of simulated results. The second and third test both involve extensive use of statistical methods such as a test of means and variances, analysis of variance, regression, and non-parametric tests.

Strategic Planning. In this stage we are concerned with designing an experimental process that will yield the desired information. The design establishes an approach for collecting original information that will provide enough knowledge about the system under study to allow valid inferences to be drawn about its behavior. Two types of objectives may emerge from the design: (1) determining the combination of parameter values that will optimize response variables, or (2) explaining the relationships between controllable factors and response variables.

Tactical Planning. This is concerned mainly with the question of efficiency and deals with the determination of how each of the test runs of the model is to be executed. Primarily, two problem areas are resolved: (1) specification of the starting conditions as they affect reaching equilibrium, and (2) the necessity to estimate the precision of the experimental results and the confidence level attributable to the conclusions or inferences drawn.

Experimentation and Sensitivity Analysis. This phase involves the running of the model and collection of desired information. Possessing many characteristics of a troubleshooting process, this stage often involves detecting flaws and oversights and making adjustments to the design as appropriate. In the sensitivity analysis, it is determined how responsive the output answers are to the values of parameters and controllable variables. The analyst can systematically vary parameter or input variable values and observe the effects upon the response of the model. Simulation is ideally suited for a sensitivity analysis because of the experimenter's degree of control. Sensitivity often becomes extremely important when many of the parameters or input variables are based on questionable data.

Interpretation. This phase involves drawing inferences from the data generated by the simulation. The user must be concerned not only with the obvious implications of the data, but also with implications or inferences that appear obvious but are a part of an interacting set of variables. In other words, before initiating corrective action based on an inference from the data, all inferences must be considered in the context of the entire system.

Implementation. Shannon (35:32) remarks that "no simulation project can be considered successfully completed until it has been accepted, understood, and used." Implementation is a key step in achieving that success. Rubenstein (33:B508–B518) found that one of the greatest causes of failure in operations research and management science projects was the user's inadequate understanding of the results, and thus a lack of implementation. Supporting this point, Gershefski (16) found that the median percentage of total model development time devoted to implementation was around 10%. Shannon (35:33) contends that this figure should be around 25% for successful implementation.

AD-A147 269 A Q-GERT NETWORK SIMULATION MODEL FOR EXAMINING PIPELINE TIME IN THE NAVY..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. M N ROMERO

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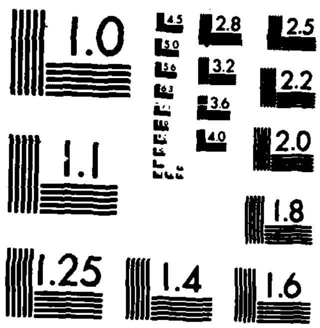
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Documentation. Careful and complete documentation of every aspect of the development of the model and its operation will reap many benefits to future users. This facilitates easier modification when required and ensures uninterrupted use of the model even when the services of the original developers are no longer available. Careful documentation also helps the modeler to learn from his mistakes.

Justification for Choosing the Simulation Approach. The choice of this approach to analyzing the J-52 repair process was based largely on its tendency to be more directly concerned with the wider organizational system issues rather than a specific objective which would be addressed by some optimization model. The system upon which the simulation model focusses in this project is the intermediate level repair cycle and not the entire J-52 logistics support effort. Drawing on stored data files and generating relevant output information, simulation offers a powerful model-based decision making tool for engine management personnel. Keen and Morton offer a comment on the value of simulation which underlies the main reason for its selection in this project: "The value of a simulation is that it often replicates a manager's environment in his or her own terms and makes it possible to test alternatives (22:46)."

Network Simulation Models

This section focusses on the third objective of this chapter - familiarizing the reader with network models and simulation languages. It accomplishes this by first discussing some of the broader concepts of network simulation models and eventually narrows the scope down to the specific language of Q-GERT (for

Queueing systems).

Activity networks and GERTs (Graphical Evaluation and Review Techniques) are discussed before introducing Q-GERT in order to assist the reader in visualizing the relationship of Q-GERT to the overall scheme of network simulation languages. Figure 7 is provided to help illustrate this relationship. Some of Q-GERTs features and limitations are also presented in this section. Further details on Q-GERT network symbology is found in Appendix H.

<u>Classification and Structure of Simulation Models</u> Simulation models are classified in a number of ways (35:7-10) including the familiar static vs. dynamic, deterministic vs stochastic, discrete vs. continuous, and iconic vs. analog. Researchers will often resort to combinations of these models to more accurately depict a complex system. Likewise, many systems or subsystems may be represented by more than one type of model independently.

The building blocks which form the structure of simulation models range from simple to complex combinations. Underlying the structure of all models, however, is the simple mathematical expression.

$$E = f(x_i, y_j)$$

where

E is a measure of the system's performance,

x_i's are the variables and parameters under our control,

y_j's are the variables and parameters we cannot control, and

f is an expression which describes the relationship between x_i, y_j, and E.

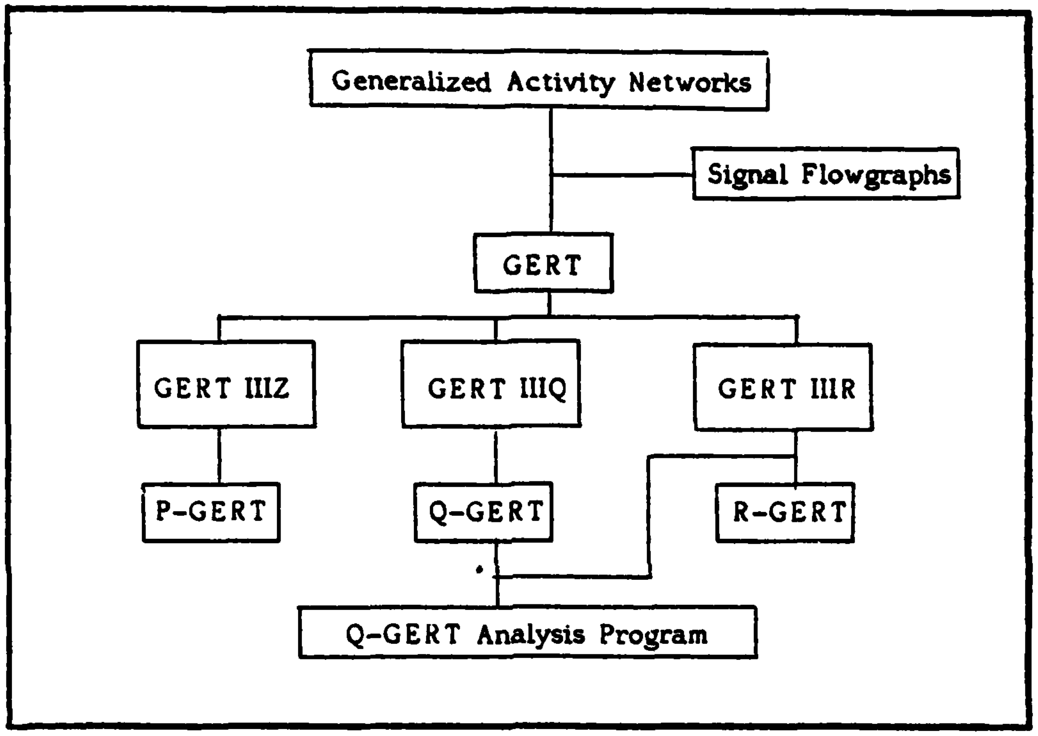


Figure 7. A Portion of the GERT Family Tree (35:16)

The structure of almost every model includes components, variables, parameters, functional relationships, constraints, and criterion functions. The extent to which these ingredients are molded together in detail will often prescribe the similarity between a model and the real system it represents. An identical correspondence gives rise to an isomorphic model, while a homomorphic model is similar in form but different in fundamental structure.

Model simplification is a concept closely related to the foregoing discussion on stucture. It entails the process of stripping away the unimportant details or the act of boldly stating certain assumptions of simpler relationships. Simplification is an essential part of developing a simulation model of a complex system, but must be given careful attention to avoid losing certain capabilities of the model (35:17,18).

Activity Networks. The complex industrial and economic systems which permeate our daily lives are rarely characterized by deterministic processes. Elmaghraby (13:325) states, however, that many of our models are possessed with the "curse of determinateness." Most systems are characterized by states and transitions from one state to another. These transitions often occur in a probabilistic fashion and can be caused by changes in time, cost, resources, location, and size. For this reason, generalized activity networks (GANs) were developed which allow managers to study these systems with probabilistic activities. Although the details of GAN's are not covered here, they generally consist of some basic "building blocks" differing primarily in the various node and branch structures and relationships.

GERT (Graphical Evaluation and Review Techique). GERT represents a special case of the GANs and is considerably easier to treat mathematically. The GERT network itself is a signal flowgraph. These graphical representations originated in the study of electrical networks in the early 1950's and have gained widespread popularity in the modeling of numerous systems. GERT employs signal flowgraph theory to model systems which are representative of semi-Markov processes (those stochastic processes characteristic of transitions from one state to another). Semi-Markov processes and signal flowgraph theory are rich in mathematical structure. Elmaghraby (13:337-356) provides in-depth mathematical coverage on the conversion of semi-Markov processes to signal flowgraph symbology, and the topic is not covered here.

The graphical representation of a GERT network usually accomplishes two objectives: (1) assisting the manager in visualizing the total system, and (2) assisting in understanding the interactions that take place among the various system components. Given its name by Pritsker (13:337), a GERT network is really a signal flowgraph* linking many operational processes with stochastic features. It focusses on system behavior, given initial starting conditions (initial state). As a modeling technique, it is applicable to problems in queueing, inventory control, reliability, quality control, and many other fields.

The discussion up to this point has focussed on the notion of GERT as a signal flowfraph representaion of a semi-Markov process. These processes are most commonly associated with systems that possess no memory; that is, actions or processes of the future are independent of the system's history. To cope with this, the analytical models of GERT gave way to the devlopment of GERTS (Graphical Evaluation and Review Technique Simulation). The same concepts applicable to the GANs mentioned earlier are applicable to GERTS, but expanded in more detail.

The main features of GERTS may by summarized under two main headings:

(1) nodes with unique characteristics, and (2) branches with unique characteristics. Elmaghraby (13:360-364) lists five capabilities offered by GERTS, but the most significant of these as it pertains to this project is the capability of accumulating statistics on the system being modeled. Time measurements at various points in the J-52 repair system, for example, are determined by the collection of time data at certain nodes. Using this feature, a wealth of information is achieved in the simulation including identification of idle activities, the amount of time incurred in various segments of the pipeline, and the backlog status at each point in the system pipeline.

GERT Justification. The decision to employ a GERT as the primary vehicle for translating the real world J-52 repair system into computer language was based on its features which make it suitable for the type activities one encounters throughout the repair process. To offer some justification for the choice of a GERT approach, a comparison with other simulation languages is helpful.

One advantage a GERT has over a PERT (Program Evaluation and Review Technique) is the absence of certain restrictions imposed on a PERT network (13:331). In a PERT network, it is not possible to repeat certain activities nor to avoid them, whereas a GERT may accomplish both of these processes. Since the engine repair process is characterized by individual repair requirements for each engine (often requiring multiple performance of the same activity), a GERT appears to conform neatly to the needs of this project. Thus, whereas a PERT would be more suitable for a steady state production process where all tranactions through the system encounter identical activities, a GERT possesses the flexibility to adapt to different requirements.

GPSS (General Purpose Simulation System) is another simulation language which bears a great deal of simularity to the GERT languages. Its ability to handle queueing problems (like GERTS) has made it a popular choice of many system simulators. GPSS is probably one of the most widely used simulation languages for job shop modeling. Its method of treating queue discipline is less straight forward than the treatment offered by a GERT. Therefore, in the interest of simplicity, the GERT approach is desireable in this project.

GERT models have been applied in a number of production settings where waiting time represents a significant loss of productive effort. Other simulation languages are available for comparison with the GERT language. However, further comparison is not carried out here. This remains as a recommendation for futher researchers who may desire to determine the most appropriate simulation language for the specific J-52 repair system problem addressed in this project.

Q-GERT (Queueing-Graphical Evaluation and Review Technique); features and limitations. Controlling production time has always been a significant but difficult task for managers concerned with production scheduling and proper inventory management. An industry survey (19) reported that less than 10% of the total production time in an average company is actual working time. The remainder is consumed by set-up time, move time, and wait time. The job sequencing and priority dispatching decisions made by production managers account for a large part of this non-productive time. Day and Hottenstein (7-11-39) reviewed over 160 research articles on the effects of scheduling and sequencing on various measures of shop performance, giving extra attention to both static and dynamic sequencing.

Networks and network analyses are playing an increasingly important role in the improvement of production systems and the elimination of many bottlenecks which result in valuable lost time. This is due largely to the ease with which systems can be modeled in network form (32:267). Q-GERT, the simulation language chosen for this project, offers just such an approach for analyzing a production system like the J-52 repair process. The application of this user-oriented, simulation language offers invaluable insights to managers of complex systems and creates a vehicle by which the system weak-points can be identified. This is precisely the rationale for developing a simulation model of the J-52 repair process. Excessive backlogs and idle activities can be identified, thus making it possible for managers to reallocate critical resources in order to increase the overall level of effectiveness and efficiency in all areas of the repair cycle.

The most significant feature of this entire simulation effort using Q-GERT is that it does more than just measure the system performance characteristics; it allows the manager to "look ahead" and predict how these measures will be affected by implementing changes in the system which are within management's control (resource allocations, facility closings, procurement of additional parts and equipment, loss or gain of manpower, and others). This is the sensitivity analysis phase and is extremely valuable to middle and upper level engine managers.

A Q-GERT network model is characterized by many features including probabalistic and deterministic branching, network feedback loops, multiple probability distributions which describe the individual activity times, queue nodes for systems where backlogs generate waiting time, and the option of assigning attributes to specific transactions flowing through the system.

The basic provisions of Q-GERT include some shop loading parameters such as the mean arrival rate of jobs, the mean processing rates of the various crews or machines involved, and the number of available machines or crews (7:11-39). It also includes the operational characteristics of the system such as the statistical distribution of the arrival rate of incoming jobs, the statistical distribution of the processing times, and the procedures for routing jobs to different activities.

The stochastic nature of these parameters normally requires that serious attention be given to the statistical distributions of the data in order to reflect the real system as closely as possible. This phase of the model development is offered as a challenge to follow-on researchers dealing with J-52 repair system problems and is not treated here. Instead, emphasis is on the development of a model which reflects the physical movement and treatment of J-52 engines (and resources) throughout the repair cycle as accurately as possible.

Q-GERT, like any other simulation language, has its shortcomings as well. Day and Hottenstein (7:11-39) list a number of limiting assumptions typically made by modelers using simulations such as Q-GERT. These include:

- Negligible transition times from one activity to the next,
- Machines and equipment that never break down,
- Levels of resources (people, tools, equipment) that are always available to perform the job,
- System performance parameters collected statistically under steady-state conditions, and
- Poisson arrival rates for arriving jobs and exponential service times.

This list of assumptions could easily extend much further. Often these assumptions can be freely made without serious degradation of the model's usefulness. On the other hand, incorrect assumptions can also render the results of a simulation model totally useless. A key point to be made here is that the objective of this thesis is to construct a Q-GERT network model which replicates the physical operation of the J-52 repair system as closely as possible. Emphasis is placed on model construction, not on application. For this reason, a number of assumptions are liberally applied to simplify the construction of the model. Follow-on work in this area can concentrate on analyzing detailed aspects of system behavior more closely, and on converting the assumptions into statistically sound parameters.

Appendix H: Fundamentals of Q-GERT Networks

Introduction

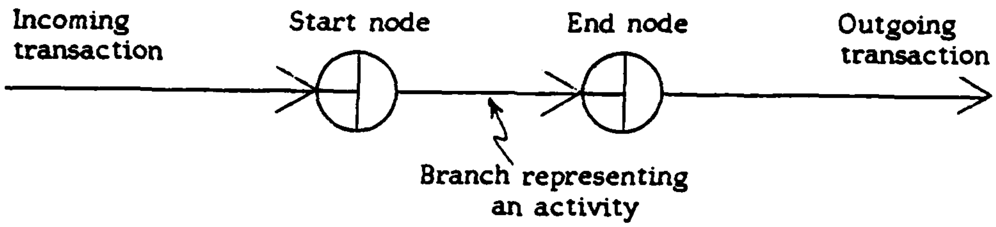
This section acquaints the reader with some of the fundamentals of the Q-GERT simulation language. In particular, some basic concepts of the Q-GERT network are described in addition to the symbology employed in a typical network. The main source for this material is Pritsker (31) who provides excellent coverage of the material in laymen's terms. The material presented here covers only a brief introduction to the concepts, and the reader is encouraged to consult Pritsker's work for further details on network model characteristics.

Q-GERT involves the graphical modeling of systems in network form. These network models provide a vehicle through which information about a system can be communicated. Q-GERT networks can be automatically analyzed to provide statistical information to the manager about the system under study.

Q-GERT employs a network philosophy called activity-on-branch in which a branch between two nodes represents an activity that involves some amount of processing time or delay. Flowing through the network are items referred to as transactions. These transactions are routed through the network according to the branching characteristics of the nodes. They can represent physical objects, information, or a combination of the two.

Different types of nodes are included in Q-GERT to allow for the modeling of complex queueing situations. Activities can be used to represent servers of the queueing system. In fact, Q-GERT networks can be developed to model sequential and/or parallel server systems. Taken as a whole, the nodes and branches of a Q-GERT model describe the structural aspects of the system.

Transactions originate at source nodes and travel along the branches of the network. Each branch has a start node and an end node as shown below.



Transactions moving across a branch are delayed in reaching the end node associated with the branch by the time required to perform the activity that the branch represents. When reaching the end node, the disposition of the transaction is determined by the node type, the status of the system, and the attributes associated with the transaction. The transaction continues through the network until no further routing can be performed. Typically, this occurs at sink nodes of the network but may occcur at other nodes to allow for the destruction of information flow.

Transactions have attribute values that allow different types of objects (or the same type of object with different attribute values) to flow through the network. Procedures are available to assign and change attribute values of transactions at the various nodes of the network.

As transactions flow through the network model, statistics are collected on travel times, the status of servers and queues, and the times at which nodes are released. Thus, a statistical data collection scheme is embedded directly in a Q-GERT network model. The Q-GERT Analysis Program employs a simulation procedure to analyze the network. The simulation procedure involves the generation of transactions, the processing of the transactions through the network, and the collection of statistics required to prepare automatically a summary report as dictated by the Q-GERT network model.

From the modeler's viewpoint, Figure 8 illustrates the types of problems which must be considered when developing a network model of a system. First, knowledge about the system components must be acquired. Second, the interaction of these components and their general behavioral characteristics must be described by some scenario. Finally, the symbology is attached to the network to portray the system behavior graphically. Once the network model is constructed and converted to computer code, it is submitted to a computer facility which possesses a Q-GERT Analysis Program. This program analyzes the network description in accordance with the modeler's specifications and produces outputs that are used in making inferences about the system under study.

Elementary Q—GERT Symbology

This section is concerned primarily with providing the reader a basic understanding of the symbology and mechanics of a Q-GERT network. The discussion covers the simplest form of a network and describes the concepts involved in its construction as well as the meaning of the symbology attached to it. The treatment of this topic is light and the reader is encouraged to learn more by consulting Pritsker's work (31), which serves as the basis for the material presented in this entire section.

One final note is necessary. Q-GERT possesses the capability for in-depth construction of a network through the use of some advanced concepts called FORTRAN inserts. This topic is not addressed here but the reader should be aware that the capability for more detailed modeling does exist. The network model of the J-52 repair system is built on basic, intermediate, and a few advanced concepts. Further refinements in detail using FORTRAN inserts are left for follow-on research.

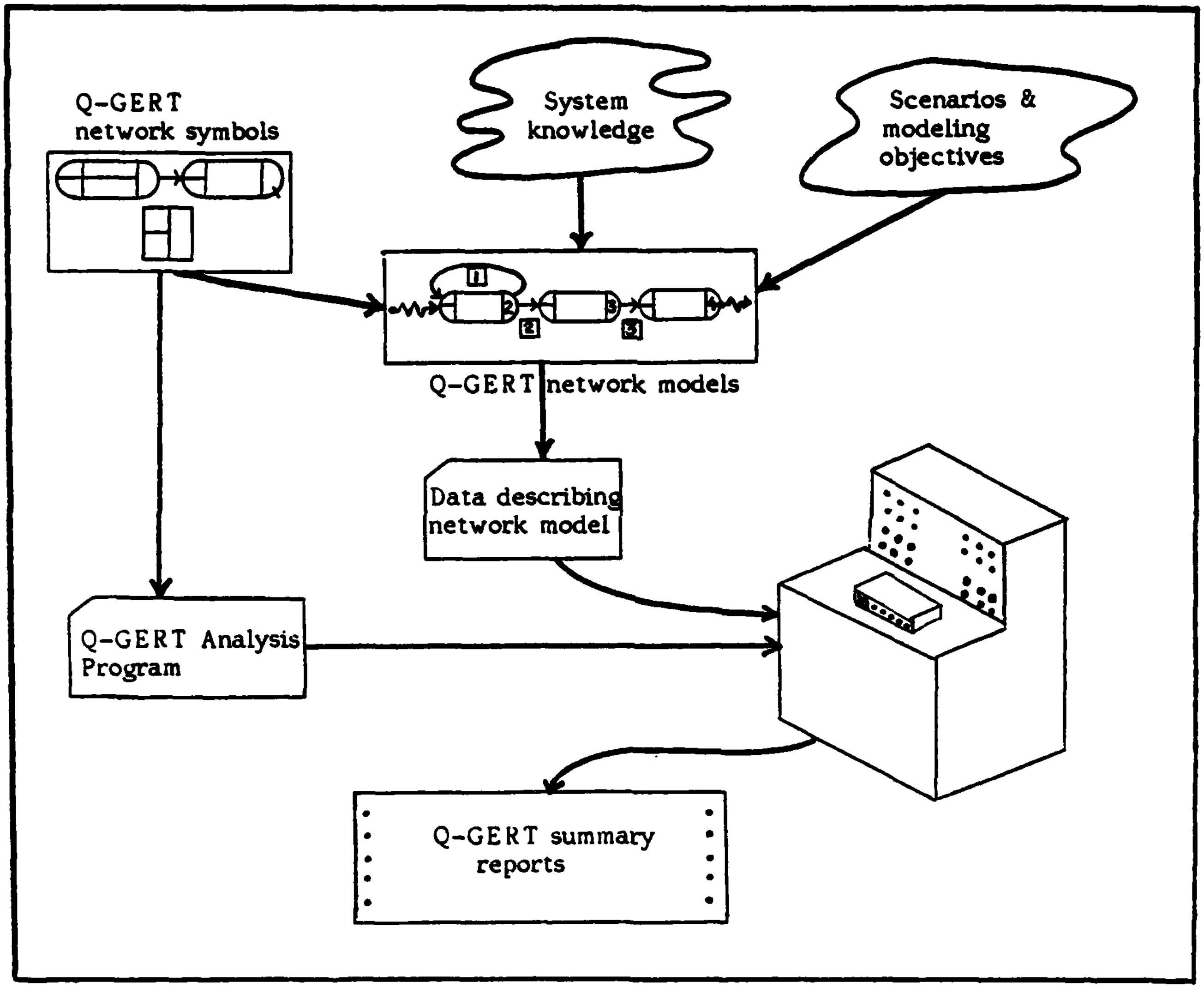
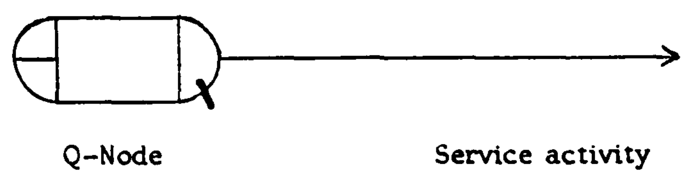


Figure 8. Components of Q-GERT Modeling and Analysis (31:10)

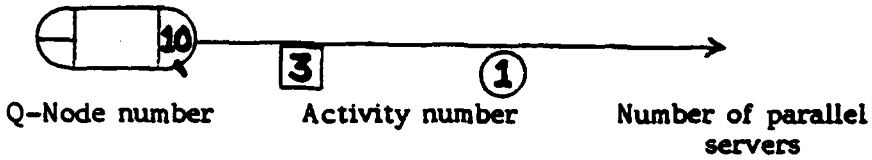
1. A One Server, Single Queue Network Model.

The discussion of the basic fundamentals of a Q-GERT network begins with the construction of a simple, three-node, three-branch model of a single server queueing system. In this system, a single line of items forms before the server. They arrive, possibly wait, are served, and depart the system. This sequence of events, activities, and decisions is referred to as a process. The entities that flow through the process are called transactions. Thus, a Q-GERT network is a graphical representation of a process and the flow of transactions through the process.

Branches in the network are graphical representations of activities performed in the process. Thus, a service operation is an activity and is modeled by a branch. The branch also represents the passage of time in a Q-GERT network; that is, the amount of time to perform the service operation is denoted by the branch. The waiting line for transactions requiring the service operation forms in the queue, denoted in the network by a Q-node. This arrangement is depicted as follows:

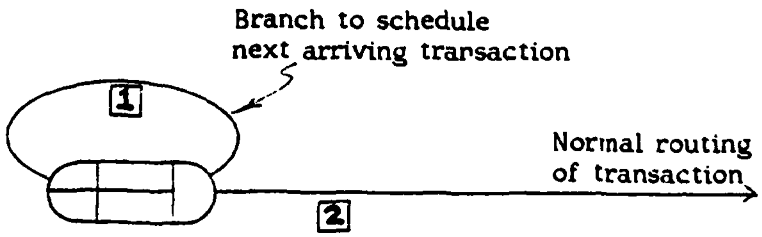


The many Q-nodes and service activities in a network are all identified numerically by their own node numbers and activity numbers. Service activities are also assigned a value which indicates the number of parallel, or concurrent, processings of transactions allowed by that branch. Q-nodes are identified visually by a "hash" mark in the lower right hand corner. The placement of the node number, activity number, and number of parallel servers is accomplished on the network as follows:



2. Modeling the Arrival of Transactions

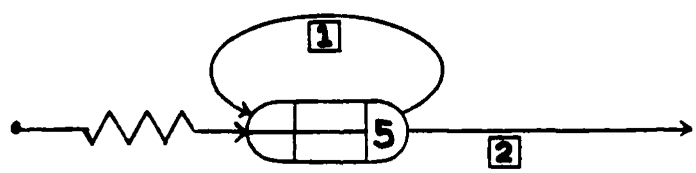
Modeling the arrival of transactions to the system is accomplished if we know, or can make assumptions about, the statistical distribution of the time between arrivals (interarrival time). This is accomplished by a node (other than a Q-node) with two branches emanating from it. One branch routes the arriving transactions on through the system in a normal fashion, while the other branch returns a transaction to the input side of the node and causes the next arriving transaction to be generated. Thus, each arrival begets the next arrival as shown in the illustration below:



It is important to note here that only Q-nodes can have servers immediately following them (identified by the number in the circle). Nodes other than Q-nodes are not allowed to have service activities immediately following them. They can, however, be identified by an activity number (the number in the square). In fact, all branches in the network are allowed to have activity numbers which just simply identifies that branch, but only Q-nodes require both an activity number and server number.

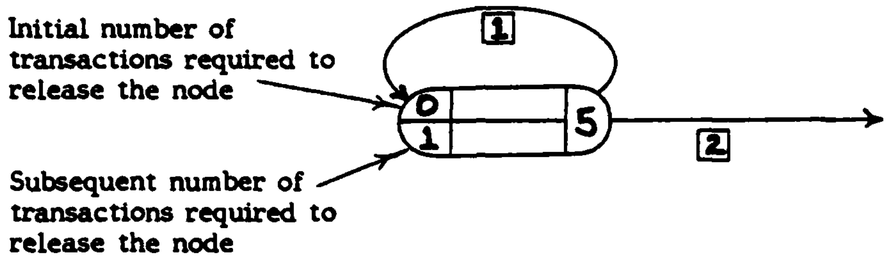
Transactions arriving at a node other than a Q-node can be processed immediately without any waiting by routing the transaction along the branches leaving the node. The semi-circle which forms the right side of the node indicates "deterministic" branching or routing. When deterministic branching is encountered, a sufficient quantity of transactions are generated internally so that transactions depart on all branches emanating from the node.

The interarrival process described above usually indicates the start of the system and is given a special symbol which identifies it as a source node as shown below:



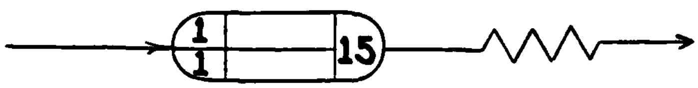
Source node

Source nodes can be viewed as an "internal generator" of transactions which flow through the system. They do not require an incoming transaction in order to be activated or released the very first time. (Releasing a node is a term used to specify that an incoming transaction can pass through the node and be routed according to the characteristics of the node). Beyond the first release of the node, however, the model must have specified the number of subsequent arrivals to the node required before it can release another transaction. This, in essence, is the interarrival process, and is accomplished as shown below.



3. Modeling Departures of Transactions

If we desire the transaction to depart the system after being serviced, this is accomplished by a single node as follows:

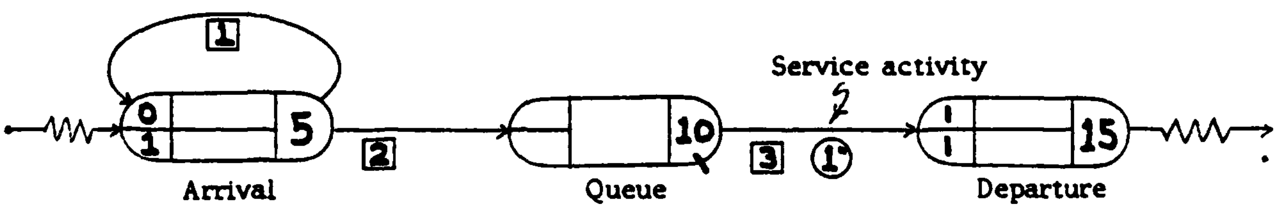


Sink node

The squiggly line is used to indicate a sink node which specifies the stopping procedure to be used when analyzing a Q-GERT network. Other methods of stopping the procedure are also available. A transaction passing through a sink node, from the modeler's viewpoint, actually "disappears" from the system. By telling the Q-GERT Analysis Program how many "sinks" are to occur, the sink node monitors the number of transactions passing through the node and terminates the run when that number has been realized. This is what is meant by specifying the stopping criteria for the simulation.

4. Combining the Concepts

The generation of a transaction, its waiting and service operations, and its departure from the system can be put together in a simple network model representing a single queue, single server process. This model is shown below.



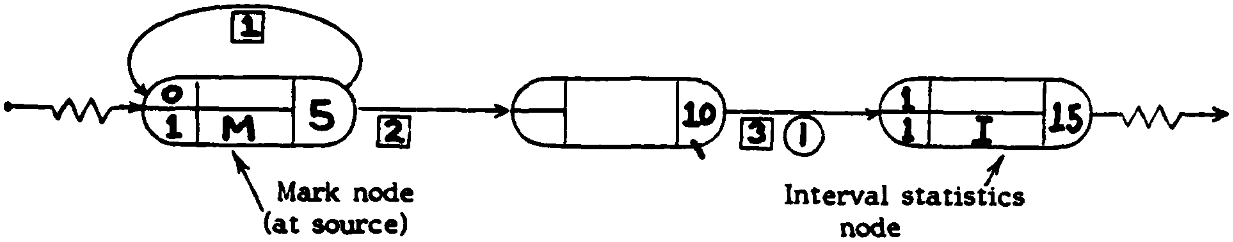
In this simple system, transactions arriving for service may find the server busy. If this is the case, the transaction takes its place in the queue with other transactions awaiting service. The order of ranking in the queue is specified by the modeler. The FIFO rule (First-In-First Out) is a commonly used queue ranking procedure. Other ways of ranking transactions in the queue are available. These include ranking in accordance with some particular attribute of the transaction. (Attributes are covered later).

5. Collecting Statistical Information

Q-GERT provides the capability for imbedding an information system within a network. The amount of time, for example, that a transaction spends in the system can be determined by computing the difference between the transaction's departure time and its arrival time. The "marking" of the time at which a transaction passes through a node is accomplished by mark nodes. This is achieved simply by placing a "M" in the lower center portion of the node. This "mark" is simply a record of when a transaction last passed through that node. Source nodes automatically mark transactions without the modeler requesting it.

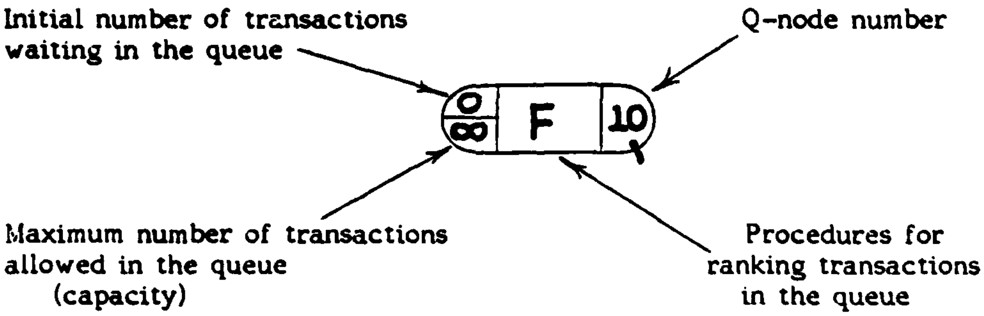
When we wish to record the amount of time spent by a transaction between two points in the system, we request an "interval statistic." This is specified at a node by placing an "I" in the lower center portion of the node. When the transaction encounters an interval statistics node, Q-GERT computes the difference between the current time and the time the transaction was last "marked." Thus, the modeler can place mark nodes and interval statistics nodes at many points in the system and determine how long the transaction spent in various segments of the system. This method of collecting statistics in a network makes Q-GERT an ideal choice for analyzing the J-52 repair system where we are concerned about bottlenecks and backlogs in the system.

The diagram on the following page represents a simple system requesting interval statistics. The transaction receives a "mark" time as it passes through node 5. It undergoes a process performed by one server at activity three, and then passes on to node 15. At node 15, the time accumulation since node 5 is collected and retained by the program.



6. Q-Node Specifications

The Q-node contains additional information not yet covered which relates to the transactions in the waiting line (queue) awaiting service. The arrangement of this information in the Q-node symbol is somewhat different than the information covered for other Q-nodes. The diagram below describes this information and shows its placement within the Q-node symbol.

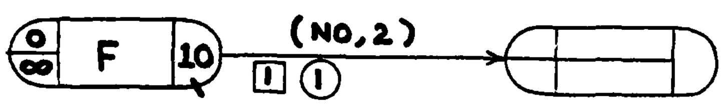


For the purposes of illustration, the zero indicates that no transactions are initially waiting in the queue, and the infinity symbol specifies an endless waiting line. Obviously, many systems will have transactions already waiting, and space constraints normally will not permit an infinite queue capacity.

7. Activity Durations

Each service activity on the branches of a Q-GERT network requires a certain amount of time to perform its task. The service time on a particular branch, for example, may be a constant two minutes for each transaction getting service. On the other hand, the exact time to perform that service activity may not be known but may instead be characterized by some random variable. This random variable may come from some statistical distribution such as the exponential, normal, lognormal, or uniform distribution.

To cope with this in Q-GERT, the service time on each branch with service activity is specified by a function type and a parameter identifier. The function type simply denotes the statistical distribution from which service times are randomly picked, and the parameter identifier is usually a parameter set number that points to a location in the program where the values of the parameters for the function are maintained. The function type and parameter identifier are prescribed within a set of parenthesis on the branch, separated by a comma. For example, a service time denoted by



indicates that the service time is represented by a random variable from the normal distribution, and the parameter values for this normal distribution are kept in parameter set two. Parameter values can refer to such statistical notions as the mean, minimum value, maximum value, or standard deviation.

Pritsker (41) provides a complete listing of the various distributions available, their Q-GERT code, and the nature of the parameter identifier.

8. Execution of the Q-GERT Model

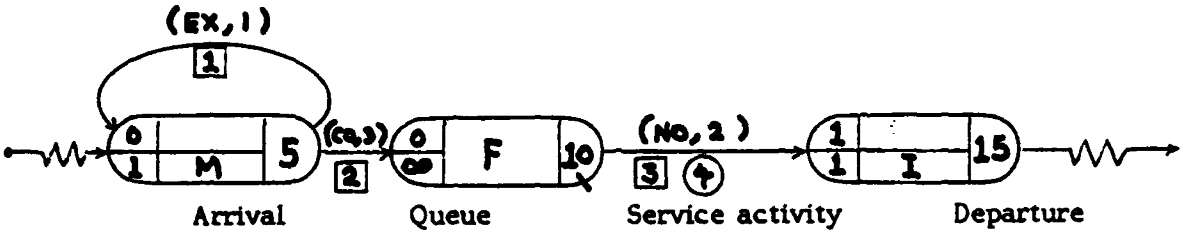
Once the system under study has been translated into a Q-GERT network model, all that remains is the transformation of the data specified on the network into a set of punched cards (or equivalent input media). A key element in this step is the preparation of the general information card. In addition to routine information such as the modeler's name, the project title or number, and the date, the general card contains critical information regarding the operating characteristics of the simulation process. This includes the number of sink node releases to end one run and the total number of runs desired by the modeler.

Imbellishments to the Basic Network

The foregoing discussion of elementary Q-GERT concepts provided the "building blocks" for this section. What follows next is a discussion of some of the imbellishments to the basic network structure just described which give modelers additional flexibility in the modeling effort.

1. Parallel Servers

Changing a single server system to a multiple server system is a simple matter, especially if all the servers are assumed to be identical. With multiple identical servers, no choice decision is required; the transactions are simply routed to the first server who becomes available. This change is made by simply changing the number in the parallel server circle from one to the desired number of parallel identical servers. Thus, in the case illustrated below, four parallel servers are available for performing identical processing on the transactions in activity three.

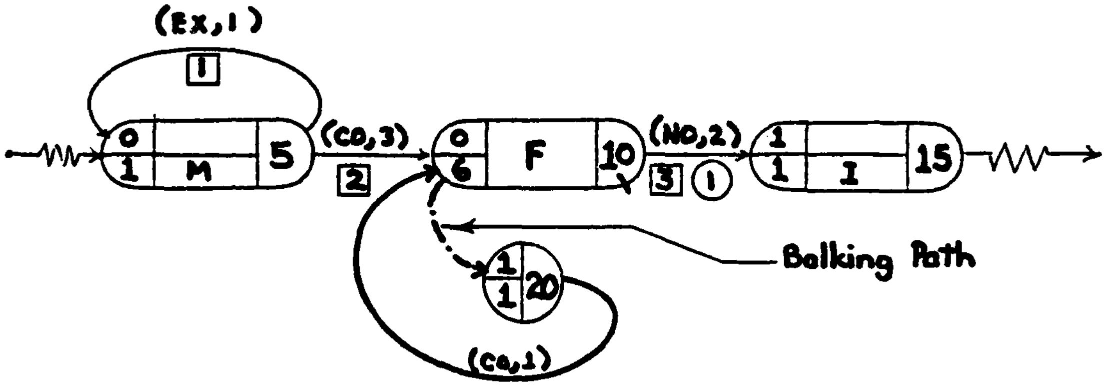


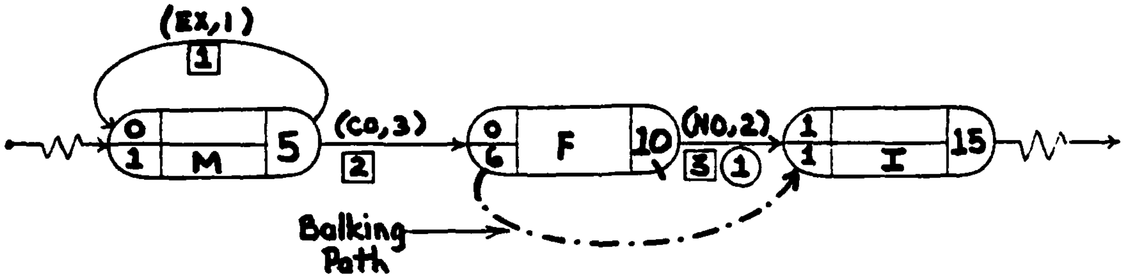
In this example, if the modeler had chosen to specify two transactions initially waiting in Q-node ten at the beginning of the simulation, this would have implied that all four servers were busy initially.

2. Balking of Transactions

The capacity of the queue is not always infinite. In some instances, there is limited waiting space for transactions seeking service. By specifying a limited queue capacity, the modeler must decide the disposition of transactions arriving and finding the queue full. One means of handling this situation in Q-GERT is through "balking." Balking occurs when a transaction does not continue to seek service if the queue is full (it goes elsewhere).

Two possibilities exist with balking: transactions can leave the system (disappear), or they can be routed to another part of the network. The omission of a balking path presumes that balking transactions are all lost to the system. The inclusion of balking is denoted by a dash-dot line for the balking path. This path could represent a situation where, for example, a customer finds the waiting queue full and decides to take care of other business while waiting for an opening in the queue in order to rejoin it. The diagram below illustrates two cases of balking. Note that the time delay is associated only with the solid line.

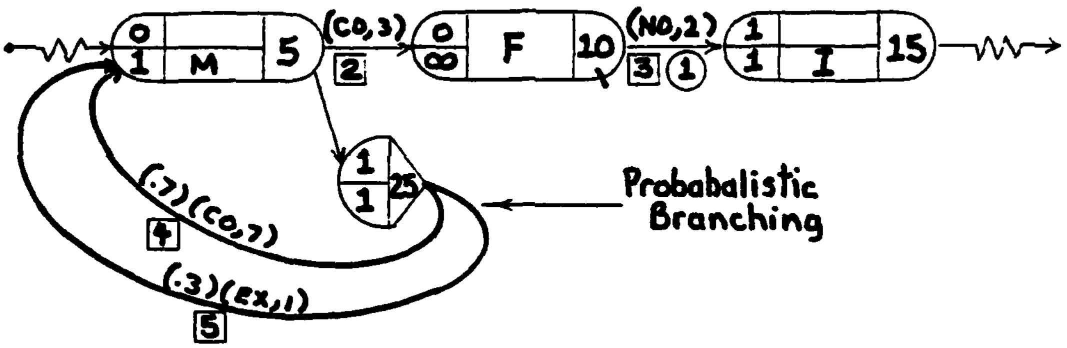




3. Complex Arrival Processes

The interarrival time discussed previously came from a single statistical distribution such as the exponential distribution. If it is known, however, that transactions arrive in accordance with two separate distributions of interarrival times, then this situation can also be modeled. This corresponds to the case, for example, where transactions display an exponential arrival pattern 70% of the time.

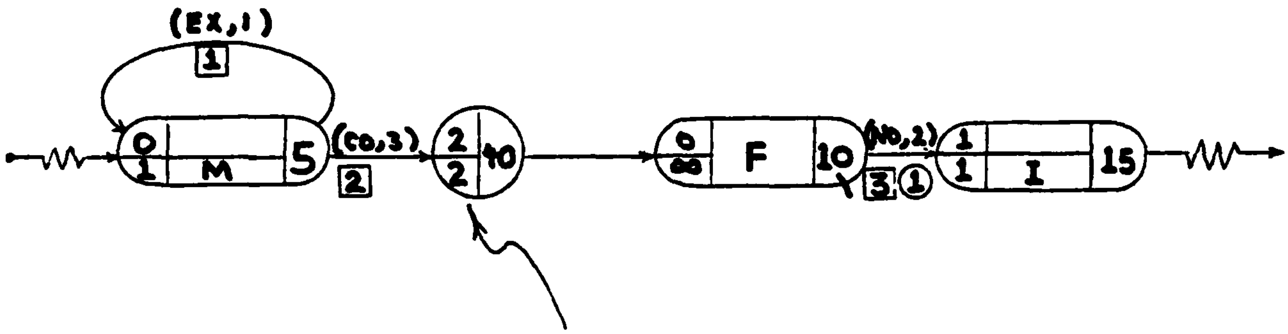
Probabalistic branching allows the modeler to represent just such a situation and is represented in the network by a triangular right hand side of the node. The individual probabilities of selecting each branch emanating from the node are assigned to the respective branches. The sum of these probabilities must, of course, equal one. The diagram below illustrates this concept. Two transactions emanate from node 5 simultaneously. The transaction going to node 25 results in a probalistic branching situation to represent the "mixed" interarrival rate.



4. Accumulating Transactions

Earlier it was mentioned that nodes other than Q-nodes specified the number of arriving transactions required to release that node. In some instances, it may be necessary to accumulate two or more transactions before service can be provided. When the required number of transactions has been accumulated, one single transaction of a new type is released to the service activity.

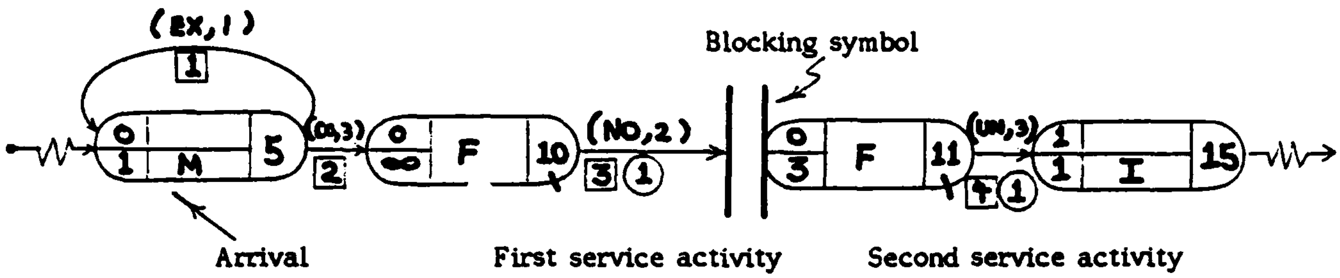
The single combined transaction carries with it the attributes specified by the modeler (attributes are covered later). Accumulation is accomplished by a simple change in the initial and subsequent number of transactions required to release the nodes as illustrated in the following diagram:



Accumulation of
2 transactions

5. Blocking of Transactions

Closely related to the concept of balking is another feature made possible by Q-GERT called blocking. Recall that in balking the transaction was either lost to the system or routed along some alternate path with a time delay when the queue was at maximum capacity. An alternative to this is to "freeze" the activity upstream until an opening occurs in the queue the transaction is attempting to join. A special symbol is employed in the network which retains the transaction at its current service activity (with service temporarily halted) until space in the subsequent Q-node becomes available. Then the action resumes as normal. Blocking is illustrated on node 11 on the following page. Service activity three will be blocked as required. Q-GERT performs all blocking, unblocking, and associated functions automatically.



The concepts described thus far can be combined in a number of sequential and parallel fashions to tailor the network to the specific description of the system under study. Attempting to illustrate all the possible routing alternatives is a formidable task and is not undertaken here.

Nevertheless, networks can be constructed to represent situations where a single server can perform a variety of different tasks. This situation is handled easily with probabilistic branching. Following the service activity, transactions can also be routed to different locations rather than all to the same destination. Such a case allows the modeler to collect statistics on any segment of the network desired or joint statistical estimates of the total time in the system.

Q—GERT Intermediate Concepts

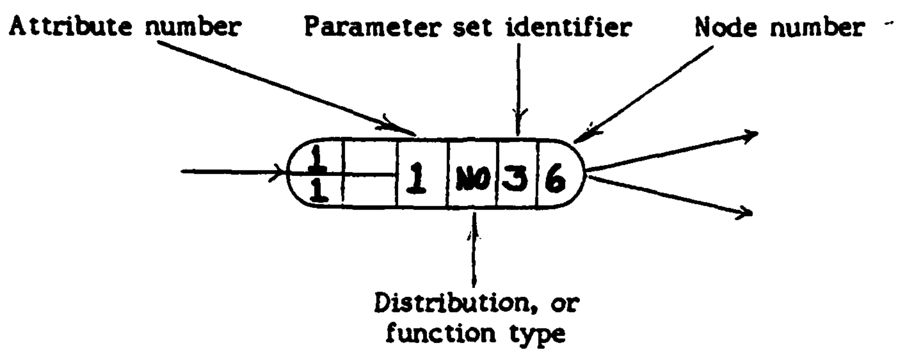
To further the background on Q-GERT concepts and symbology, some of the intermediate concepts are presented next. These intermediate concepts relate to associating certain attributes with transactions, selecting among available servers and/or queues, and matching transactions with common attributes. Assigning attributes and using Selector nodes and Match nodes affords the modeler tremendous flexibility in being able to replicate a real life system.

1. Assigning Attributes to Transactions

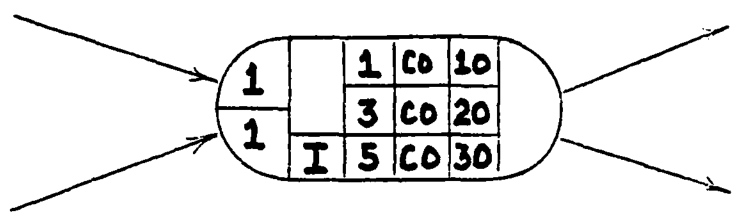
Attributes are values assigned to a transaction. These attribute values give identity to a transaction and are used to distinguish between types of transactions or to differentiate between transactions of the same basic type. This feature allows the network to process transactions differently based on the assigned attribute values.

Attributes are used to affect three fundamental aspects of network logic: the specification of time required for a service activity to process a transaction, the ranking of transactions in queues, and the routing of transactions from a node. The number of attributes associated with each transaction is defined by the modeler through input data. Any node in the network can be used to assign attribute values. The "mark" time of a transaction, automatically assigned at source nodes, is one attribute that all transactions possess.

When assigning attribute values to transactions at any given node, two pieces of information must be prescribed: the attribute number and the computational procedure for determining the actual value of that attribute. The attribute number is simply any integer. The computational procedure, on the other hand, is similar to that for the activity times. That is, a distribution function type and parameter identifier are used to generate the attribute value. This information is placed in the central portion of the node just prior to the node number. The convention for this notation is shown on the following page. Attribute number one for each transaction traversing node 6 receives a value which is randomly generated from the normal distribution function specified by parameter set 3.

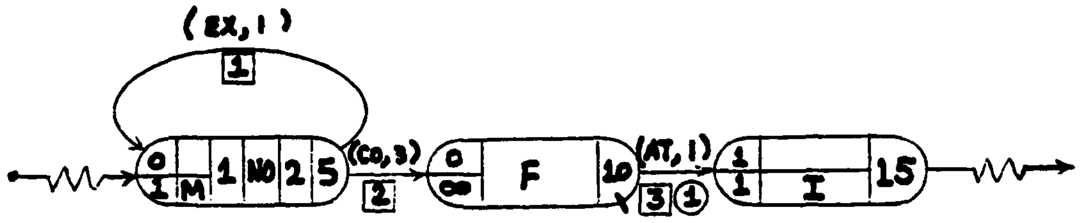


Multiple attribute assignments are easily accomplished at a single node. In the instance below, attributes number one, three, and five are assigned constant values of 10, 20, and 30, respectively, at node 7. Nodes can also change existing attribute values in addition to assigning new ones.



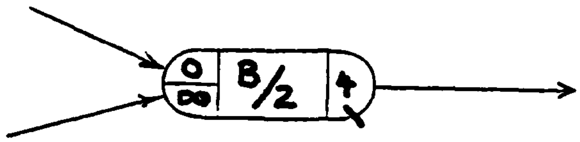
Attribute values are used to distinguish between different types of transactions as well as to differentiate transactions of the same basic type. Attribute number one, for example, could identify vehicle types by assigning a constant of 1 for cars or a constant of 2 for trucks. Similarly, attribute number two could distinguish between truck types by assigning a constant of 10 for 10-ton trucks or a constant of 20 for 20-ton trucks. It logically follows from this that the three models of the J-52 (P-6, P-8, P-408) could easily be identified in a network by designating one of the attributes as the engine model identifier. Then a constant of 6, 8, or 408 could be assigned to this attribute of the individual transactions as appropriate.

Attribute numbers can also be used to identify the service or activity time required for that transaction. This is accomplished by using the AT specification for a branch (for ATtribute). Thus, if the specification (AT,1) is assigned to a branch, then the time for a transaction to traverse that branch is whatever value is currently held by attribute one for that transaction. This is illustrated in the diagram which follows:



The actual mechanics of assigning attribute values to transactions are accomplished through the use of VAS (Value Assignment) input card. The details of this procedure are covered thoroughly in Chapter 5 of Pritsker (41:132-188) and are not dealt with here.

Another handy feature of attributes is the ability to rank transactions in the queue in accordance with the value of a specified attribute. In the illustration on the following page, the B/2 ranking specifies that the transaction in the queue with the biggest value of attribute two is given priority for processing. Thus, it will become the first one to leave the queue whenever a server becomes available.

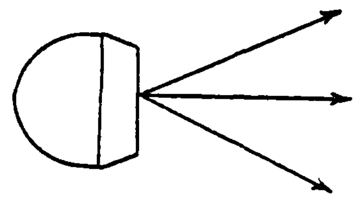


If the queue ranking rule is to be determined by the smallest value of attribute two, then the notation S/2 is specified. Similarly, B/M and S/M rank transactions in the queue based on the biggest value and smallest value of mark time, respectively. The usefulness of this convention is readily apparent in situations where it is desired to process transactions which have been in the system the longest.

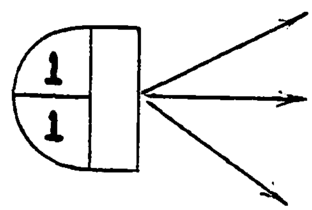
The elementary aspects of deterministic and probabilistic branching were discussed previously. With attributes, Q-GERT allows the modeler to base branching decisions on the current status of the system or on attribute values assigned to transactions. This is known as conditional branching. Two types of conditional branching occur when using attributes: conditional branching-take first, and conditional branching-take all.

In both cases, condition codes are specified on the branches emanating from the node. The condition must be satisfied if the transaction is to be routed along that branch. These codes relate to four system or attribute characteristics: time at which routing is to occur, the prior release of a node, the value of an attribute compared to some criterion value, and the value of an attribute compared to the value of another attribute.

The nodes for the two types of branching are constructed differently to allow easy recognition straight from the network. The node for conditional branching-take first is shown on the following page.



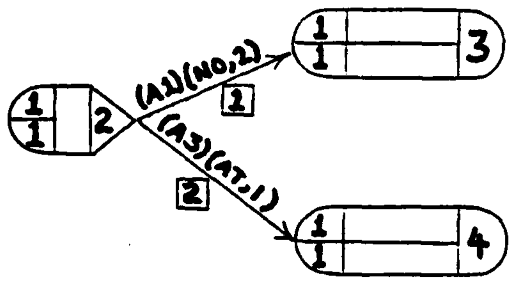
The conditions specified on the branches are evaluated in order and the transaction is routed along the first branch for which the condition is satisfied. The first branch condition satisfied receives the transaction and the remaining branches are not evaluated. The node for conditional branching-take all is shown in the following diagram, where every condition is evaluated and a duplicate transaction is routed along each branch for which the condition is satisfied.



The order in which branches are evaluated is specified by the modeler in the input data. Also, there are 28 possible condition codes that can be specified for a branch. These are too numerous to cover here and the reader is encouraged to consult Pritsker's text.

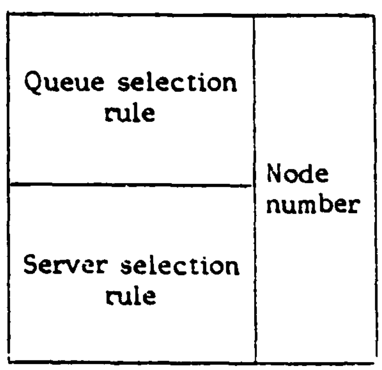
Attributes also enhance the procedures for probabilistic branching as well. No major symbology change is required and the procedure behaves in a very similar way as the conventional means of probabilistic branching. The main extension feature is that rather than having branches with fixed probabilities, attributes possessing a value for a probability can be assigned to the branches.

In the example below, transactions are routed to either activity 1 or activity 2 depending on the probability values assigned to attributes 1 and 3, respectively.

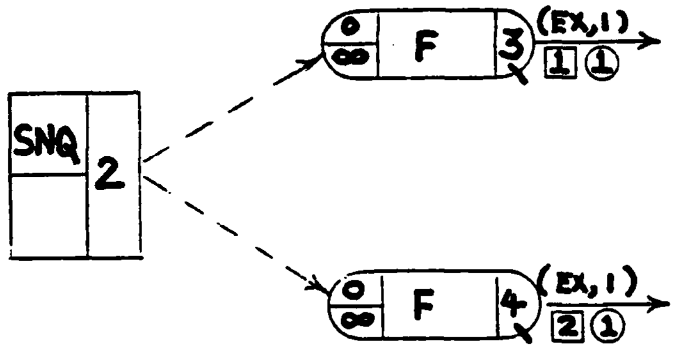


2. Selector Nodes (S-nodes)

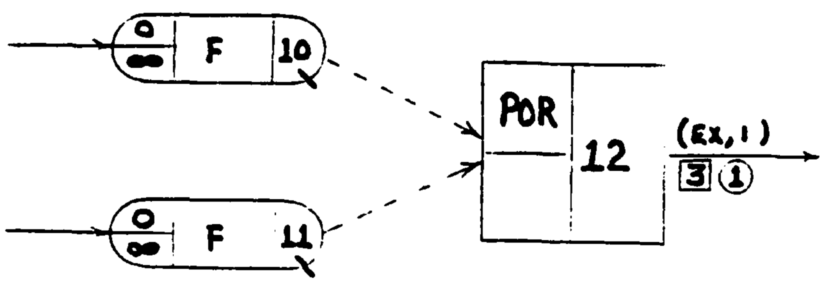
Selector nodes are incorporated in a Q-GERT network to give the modeler the ability to invoke certain selection rules for governing the flow pattern of transactions. Two general situations exist which make S-nodes extremely useful: a network of parallel queues before or after a single service activity, and a single queue supplying transactions to a network of parallel, non-identical servers. The symbology for an S-node is illustrated below showing the location of the appropriate selection rules.



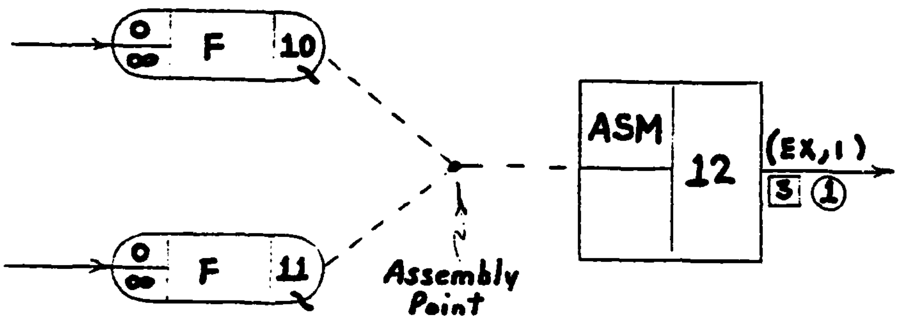
The first case involves the routing of transactions to parallel queues. Transactions arrive along a single branch and must join one of the parallel queues. A decision must be made regarding which queue to join. The S-node provides a "look ahead" capability by evaluating the queues linked to the S-node and selecting one of the queues according to some selection rule specified by the modeler. Fourteen queue selection rules are available and include such codes as SNQ (smallest number in the queue), LNQ (largest number in the queue), and RAN (random assignment). This concept is illustrated below.



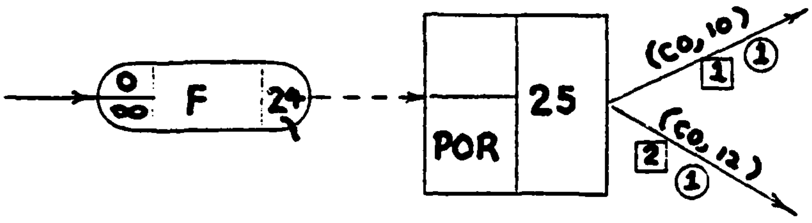
The second situation (shown below) is similar to the first and involves selection of a transaction from parallel queues to feed into a single service activity. That is, transactions are waiting in each of the parallel queues for the single server to become available. When the server finally becomes available, a choice is made by the selector node (via a queue selection rule) as to which queue will provide the next transaction.



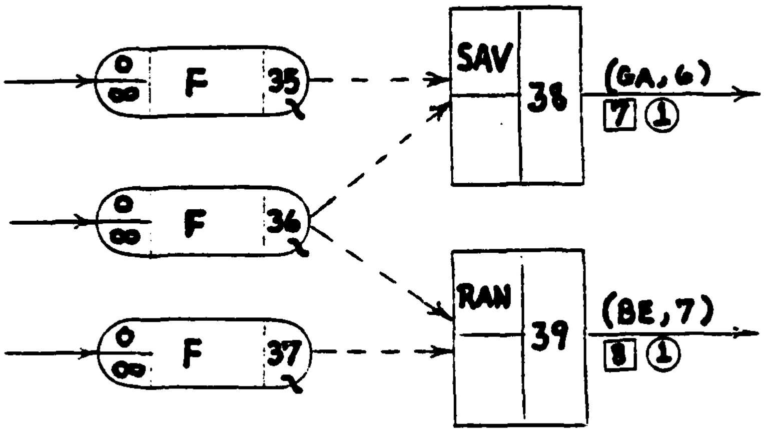
A slight modification to this scheme results in a very useful feature by Q-GERT. The transactions in the queues may represent various subcomponents of a major assembly or of a project and the server only processes "assembled" transactions. Thus, the transactions in each of the queues must be merged together to form an assembled unit before the server can process it. This case arises, for example, when an engine arrives for repair and must be merged with a repair crew and an engine stand before the accomplishment of a service activity (repair job) can take place. The queue selection rule ASM (Assembly Selection Mode) accomplishes this merger and passes the completed unit on to the server, as shown below.



The third case where selector nodes are helpful is when a single queue holds transactions which feed into two or more parallel, non-identical servers. The S-node invokes the prescribed server selection rule to make the proper choice of servers. Eight selection rules are available and it is important to note that the server selection rule applies only to a choice among free servers. This server selection case is illustrated on the following page.

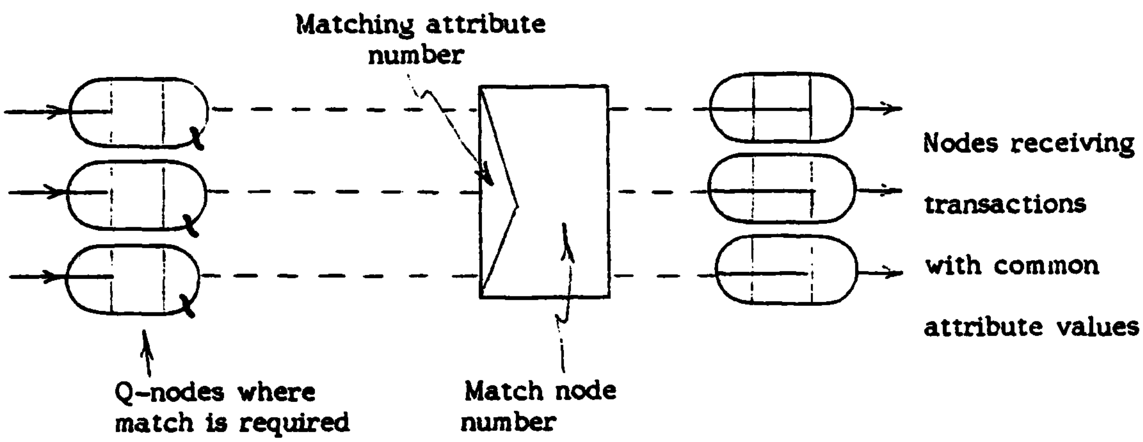


As with the simple structures, balking and blocking are also permitted at S-nodes. In addition, many complex structures can be put together such as the one shown below where two S-nodes decide the routing of transactions. No attempt is made here to try to cover the more elaborate network structures.



3. Match Nodes

The last of the intermediate Q-GERT concepts discussed is the match node. Match nodes are nodes that match transactions residing in specified Q-nodes that have equal values for a specified attribute. The match node (shown below) removes these transactions from the Q-nodes and routes each transaction to a specified node. The difference between a match node and an S-node with the ASM queue selection rule is that a match node requires the transactions to have the same values for a specified attribute, while the S-node does not.



When a transaction in each of the Q-nodes on the left has a common value for the matching attribute number, the match node routes these transactions individually to their respective receiving node. Match nodes are often employed as logic switches in a network. They are also used to model situations in which a transaction must wait for a signal before proceeding in the network.

Advanced Q—GERT Concepts

A number of situations exist in production, finances, and several other industries where it is necessary to assign certain resources to a transaction in order to successfully process the transaction. Such is the case in the J-52 repair system, for example, where an engine requiring repair must have an available workstand and repair crew assigned to it before repair can be accomplished. In Q-GERT, it is possible to halt the flow of a transaction until a specific resource type becomes available to be allocated to the transaction. Allocate and Free nodes are the mechanisms which accomplish this. Alter nodes also play a role in determining resource capacity. Together, these three nodes represent only a few of Q-GERT's more advanced features, and are discussed briefly in this section.

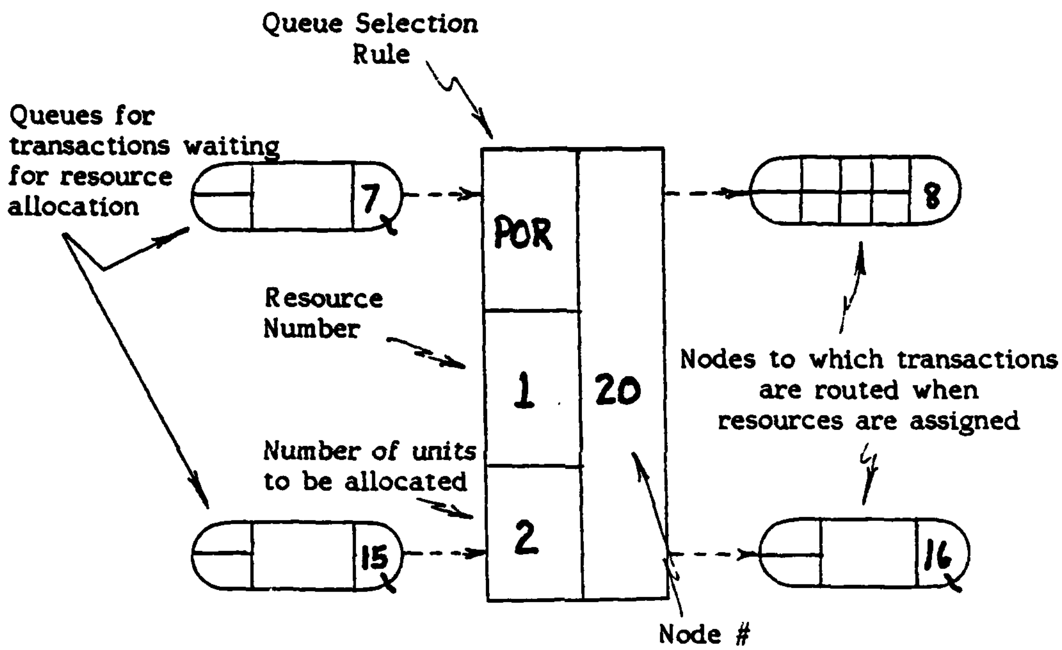
1. Allocate Nodes

"A resource is defined as an entity which is required by a transaction before the transaction can proceed through the network (31:355)." The different types of resources (eg., crews, machines, space, stands) are defined by the modeler. For each resource type, there are three critical pieces of information required by the network: the resource number, the number of units of that resource available, and the total resource capacity.

A resource is allocated at various nodes in the network. That is, it can be allocated to transactions waiting in a queue at one point, and later allocated to transactions waiting in another queue. Once it is allocated to a transaction, a particular resource unit cannot be reallocated until it is no longer being used. When it finally becomes freed, an interrogation procedure is employed by Q-GERT to determine the next transaction to which the available resource should be allocated.

As previously mentioned, the allocate nodes assign, or allocate, available resources to transactions waiting in a queue. Thus, preceding an allocate node are one or more queue nodes. When resource units become available in the system, the allocate node selects from one of the queues a transaction requiring that type of resource. The selected transaction is routed from its queue through the allocate node where it picks up a resource, and the matched pair is routed on to a designated node. Resources allocated by an allocate node are taken out of an available resource pool until they become free at some later point in the network.

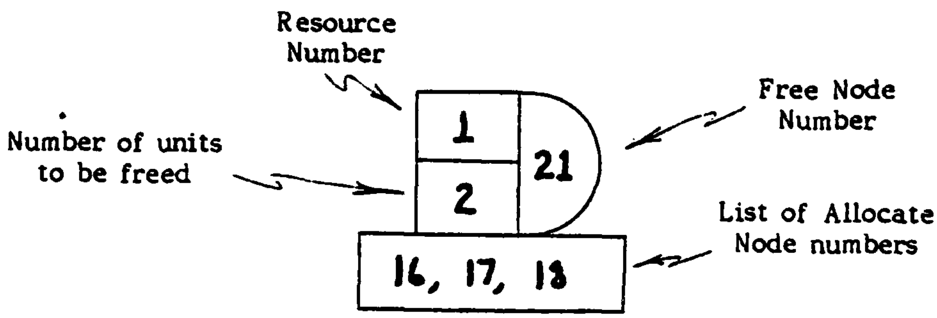
The basic symbol for an allocate node is shown below. In this particular



situation, transactions in queue node 7 are assigned two units of resource number 1 by node 20, and the matched pair is forwarded on to node 8. The POR queue selection rule (Preferred Order) merely specifies that node 7 will be interrogated first for available transactions before node 15. Many other queue selection rules are available including CYC (Cyclic Priority), RAN (Random Priority), LNQ (Largest Number of transactions in the Queue), and SNQ (Smallest Number of transactions in the Queue).

2. Free Nodes

Once a resource has accomplished its purpose with a transaction, the desire is then to free it up so that it becomes available for reallocation to another transaction. The free node accomplishes this purpose. A transaction arriving at a free node releases that node. This, in turn, causes a specified number of units of the resource to be freed up and placed back into the pool of available resources. Thus, the free node allows transactions to make resources available. The following diagram points out some of the features of the free node symbol.

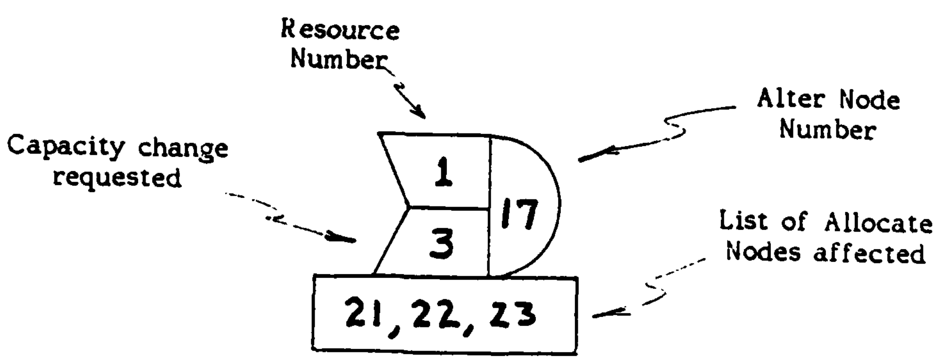


Note that the list of allocate nodes in the box at the bottom of the free node prescribes the order in which allocate nodes are to be polled as resources become available. The objective achieved here is a smooth, orderly assignment of resources which minimizes their idle time.

3. Alter Nodes

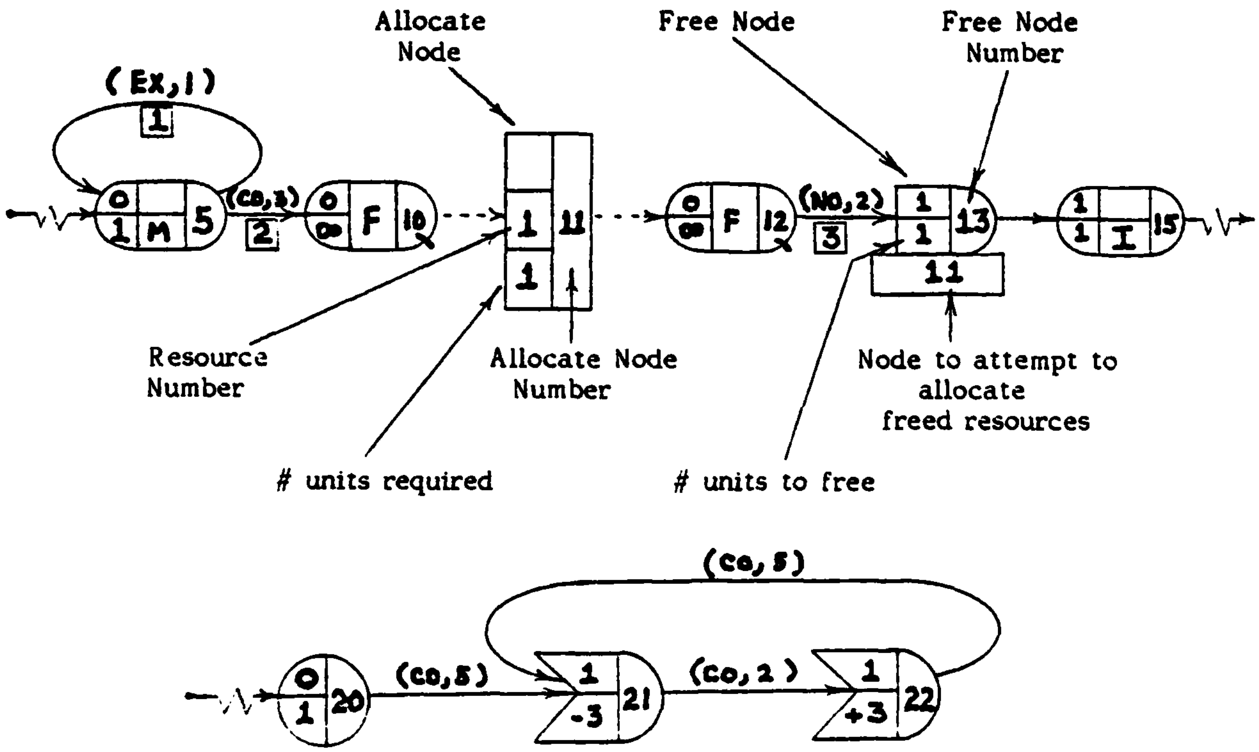
The last of the advanced Q-GERT concepts to be discussed is the alter node. This useful feature allows the modeler to alter or change the total resource capacity. For example, it is often desirable to model situations where server resources take lunch breaks or where machinery resources are inducted for preventive maintenance. In such cases the desire is to decrease the total number of resources available. Then some time later, these resources may be brought back into the picture. Alter nodes accomplish this by making adjustments to the total number of resource units available in the pool for allocation.

The alter node is placed in the network at locations where it is desirable for transactions to cause a change (positive or negative) in the capacity of a resource type. Alter nodes occur in a disjoint network (physically separated from the main part of the network) and the capacity of the specified resource number is changed by some interger number of units. The symbology which follows illustrates the alter node concept. Note again the allocate nodes at the bottom which are affected by the change in a resource capacity.



4. Combining the Concepts

The diagram on the following page illustrates a simple one server (one resource) single queue model which combines some of the concepts just discussed. The server is resource number one and there are a total of five servers available for assignment. Transactions are generated at node five and they wait in queue node ten until server resources are allocated by allocate node eleven. Once the server completes the job on the transaction, free node thirteen frees up the server for reallocation by node eleven. Note that the disjoint network specifies that the total number of units of server resources changes by minus three at node twenty-one and remains this way for two time units. Then node twenty-two increases them by plus three to resume normal capacity for five times units. This could replicate, for example, a situation where only two repair crews are available on weekends but five during the normal work week.



The Final Step

This completes the discussion of Q-GERT concepts and symbology. Having integrated the various symbols into a complete Q-GERT network, the next step is translating the network symbology into computer code acceptable to the Q-GERT Analysis Program. Chapter 3 of Pritsker (31:52-90) covers this phase in detail and the topic is not addressed here. This step, however, is a crucial part of the simulation effort and should not be treated casually. The quality of the output information received is determined largely by the care with which critical parameters, values, and several selection rules are chosen. Pritsker discusses not only the intricate detail of coding the input data, but also the procedures for specifying how statistical data is to be collected. In addition, an explanation of the Q-GERT Analysis Program Output Report is also provided to assist the modeler in interpreting the results.

Appendix I: Input Code for Q-GERT Analysis Program

```
GEN,ROMERO,THESIS,09,26,1984,13,3,9999,7264.,5,S,1000.,5*
*
*                    S O U R C E   N O D E S
*
SOU,  1,  0,  1,  D,  M*          Interarrival rate-unscheduled removals
SOU,  2,  0,  1,  D,  M*          Interarrival rate-scheduled removals
*
*                  R E G U L A R   N O D E S
*
REG,  3,  1,  1,  P*              Branching for engine designation
REG,  4,  1,  1,  P*              Branching for engine designation
REG,  5,  1,  1,  D*              Designate P-6
REG,  6,  1,  1,  D*              Designate P-8
REG,  7,  1,  1,  D*              Designate P-408
REG,  14, 1,  1,  P*              Designate "I" level repair
REG,  24, 1,  1,  P*              Branching for minor/major repair
REG,  26, 1,  1,  D*              Designate minor repair
REG,  34, 1,  1,  F*              Branching for repair crew assignment
REG,  41, 1,  1,  F*              Branching for initial repair
REG,  42, 1,  1,  P*              Branching for AWP/AWM
REG,  43, 1,  1,  D*              Junction
REG,  44, 1,  1,  F*              Branching for minor/major AWP
REG,  45, 1,  1,  F*              Branching for crew re-allocation
REG,  50, 1,  1,  F*              Branching for release of crew
REG,  53, 1,  1,  D*              Junction
REG,  54, 1,  1,  F*              Branching for minor/major AWM
REG,  55, 1,  1,  F*              Branching for crew re-allocation
REG,  60, 1,  1,  F*              Branching for subsequent repair
REG,  61, 1,  1,  D*              Junction to build-up
REG,  62, 1,  1,  F*              Branching for release of crew
REG,  66, 1,  1,  P*              Branching for post-maint. test cell run
REG,  85, 1,  1,  P*              Branching for minor/major repair
REG,  86, 1,  1,  D*              Designate minor repair
REG,  87, 1,  1,  D*              Designate major repair
REG,  89, 1,  1,  F*              Branching for QEC build-up (if required)
REG,  90, 1,  1,  D*              Designate Ready For Issue (RFI)
*
*               S T A T I S T I C S   N O D E S
*
STA,  8,  1,  1,  D,  I*          Transit to SSC
STA,  11, 1,  1,  P,  I*          Transit to IMA & processing
STA,  12, 1,  1,  D,  I*          Transit to depot
STA,  17, 1,  1,  D,  I*          Test cell crew allocation time
STA,  20, 1,  1,  D,  I*          Test cell allocation time
STA,  21, 1,  1,  D,  I*          Pre-induction test cell run
STA,  30, 1,  1,  D,  I*          QEC crew & workstand allocation time
STA,  31, 1,  1,  D,  I*          QEC removal time
STA,  69, 1,  1,  D,  I*          Test cell crew allocation time
STA,  72, 1,  1,  D,  I*          Test cell allocation time
```

```
STA,  73, 1,   1,  D,  I*           Post-maintenance test cell run
STA,  80, 1,   1,  D,  I*           QEC crew & workstand allocation time
STA,  81, 1,   1,  D,  I*           QEC build-up time
*
*                 S I N K   N O D E S
*
SIN,  13, 1,   1,  D,  I*           Depot repair time
SIN,  84, 1,   1,  D,  I*           Transit to user
SIN,  88, 1,   1,  D,  I*           Initial repair time
*
*                 Q U E U E   N O D E S
*
QUE,  9,  ,    ,   D,  F*           Awaiting transit to IMA
QUE,  10, ,    ,   D,  F*           Awaiting processing at IMA
QUE,  15, ,    ,   D,  F,,,,16*     Awaiting test cell crew
QUE,  18, ,    ,   D,  F,,,,19*     Awaiting test cell
QUE,  25, ,    ,   D,  F,,,,27*     Awaiting QEC crew
QUE,  28, ,    ,   D,  F,,,,29*     Awaiting QEC workstand
QUE,  35, ,    ,   D,  F,,,,36*     Awaiting P-6/8 crew
QUE,  37, ,    ,   D,  F,,,,38*     Awaiting P-408 crew
QUE,  39, ,    ,   D,  F,,,,40*     Awaiting repair workstand
QUE,  46, ,    ,   D,  F,,,,47*     Awaiting P-6/8 crew re-allocation
QUE,  48, ,    ,   D,  F,,,,49*     Awaiting P-408 crew re-allocation
QUE,  56, ,    ,   D,  F,,,,57*     Awaiting P-6/8 crew re-allocation
QUE,  58, ,    ,   D,  F,,,,59*     Awaiting P-408 crew re-allocation
QUE,  67, ,    ,   D,  F,,,,68*     Awaiting test cell crew
QUE,  70, ,    ,   D,  F,,,,71*     Awaiting test cell
QUE,  76, ,    ,   D,  F,,,,77*     Awaiting QEC crew
QUE,  78, ,    ,   D,  F,,,,79*     Awaiting QEC workstand
*
*                 A L L O C A T E   N O D E S
*
ALL,  16, POR,  2,  1,  15/17*      Allocation of test cell crew
ALL,  19, POR,  7,  1,  18/20*      Allocation of test cell
ALL,  27, POR,  1,  1,  25/28*      Allocation of QEC crew
ALL,  29, POR,  5,  1,  28/30*      Allocation of QEC workstand
ALL,  36, POR,  3,  1,  35/39*      Allocation of P-6/8 repair crew
ALL,  38, POR,  4,  1,  37/39*      Allocation of P-408 repair crew
ALL,  40, POR,  6,  1,  39/41*      Allocation of repair workstand
ALL,  47, POR,  3,  1,  46/60*      Allocation of P-6/8 repair crew
ALL,  49, POR,  4,  1,  48/60*      Allocation of P-408 repair crew
ALL,  57, POR,  3,  1,  56/60*      Allocation of P-6/8 repair crew
ALL,  59, POR,  4,  1,  58/60*      Allocation of P-408 repair crew
ALL,  68, POR,  2,  1,  67/69*      Allocation of test cell crew
ALL,  71, POR,  7,  1,  70/72*      Allocation of test cell
ALL,  77, POR,  1,  1,  76/78*      Allocation of QEC crew
ALL,  79, POR,  5,  1,  78/80*      Allocation of QEC workstand
*
*                 F R E E   N O D E S
*
FRE,  22, D,  2,  1,  68, 16*       Release test cell crew
FRE,  23, D,  7,  1,  71, 19*       Release test cell
FRE,  32, D,  1,  1,  77, 27*       Release QEC crew
FRE,  33, D,  5,  1,  79, 29*       Release QEC workstand
```

```
FRE,  51, D,  3,  1,  47, 57, 36*     Release P-6/8 repair crew
FRE,  52, D,  4,  1,  49, 59, 38*     Release P-408 repair crew
FRE,  63, D,  3,  1,  47, 57, 36*     Release P-6/8 repair crew
FRE,  64, D,  4,  1,  49, 59, 38*     Release P-408 repair crew
FRE,  65, D,  6,  1,  40*             Release repair workstand
FRE,  74, D,  2,  1,  68, 16*         Release test cell crew
FRE,  75, P,  7,  1,  71, 19*         Release test cell
FRE,  82, D,  1,  1,  77, 27*         Release QEC crew
FRE,  83, D,  5,  1,  79, 29*         Release QEC workstand
*
*            R E S O U R C E   A S S I G N M E N T S
*
RES,  1,  2,  77, 27*                 QEC crew
RES,  2,  2,  68, 16*                 Test cell crew
RES,  3,  10, 47, 57, 36*             P-6/8 repair crew
RES,  4,  2,  49, 59, 38*             P-408 repair crew
RES,  5,  4,  79, 29*                 QEC workstand
RES,  6,  16, 40*                     Repair workstands
RES,  7,  2,  71, 19*                 Test cells
*
*            V A L U E   A S S I G N M E N T S
*
VAS,  1,  2,  CO,1.0, 5, CO,1.0*      Type removal/engine status
VAS,  2,  2,  CO,2.0, 5, CO,1.0*      Type removal/engine status
VAS,  5,  1,  CO,    6.0*             Engine model designator
VAS,  6,  1,  CO,    8.0*             Engine model designator
VAS,  7,  1,  CO,    408.0*           Engine model designator
VAS,  12, 4,  CO,    2.0*             Repair capability
VAS,  13, 5,  CO,    2.0*             Engine status
VAS,  14, 4,  CO,    1.0*             Repair capability
VAS,  25, 3,  CO,    2.0*             Extent of repair
VAS,  26, 3,  CO,    1.0*             Extent of repair
VAS,  86, 3,  CO,    1.0*             Extent of repair
VAS,  87, 3,  CO,    2.0*             Extent of repair
VAS,  81, 5,  CO,    2.0*             Engine status
VAS,  90, 5,  CO,    2.0*             Engine status
*
*            A C T I V I T I E S
*
ACT,  1,  1,  EX, 1,  1*              Interarrival rate; unscheduled removals
ACT,  2,  2,  EX, 2,  2*              Interarrival rate; scheduled removals
ACT,  1,  3*                          Connector
ACT,  2,  4*                          Connector
ACT,  3,  5, , , , ,  .2*             Probability of P-6
ACT,  3,  6, , , , ,  .6*             Probability of P-8
ACT,  3,  7, , , , ,  .2*             Probability of P-408
ACT,  4,  5, , , , ,  .2*             Probability of P-6
ACT,  4,  6, , , , ,  .6*             Probability of P-8
ACT,  4,  7, , , , ,  .2*             Probability of P-408
ACT,  5,  8,  LO, 3,  3*              P-6 transit to SSC
ACT,  6,  8,  LO, 3,  4*              P-8 transit to SSC
ACT,  7,  8,  LO, 3,  5*              P-408 transit to SSC
ACT,  8,  9*                          Connector
ACT,  9,  10, NO, 4,  6,  1*          Transit to IMA
```

```
ACT,  10, 11, NO, 5,  7,  2*                  Administrative processing
ACT,  11, 12, NO, 6, 8, ,.05*                 Transit to depot
ACT,  12, 13, LO, 7,  9*                      Depot repair
ACT,  11, 14, , ,  32,  ,  .95*               To IMA
ACT,  14, 15, , ,  33,  ,  .97*               To test cell
ACT,  17, 18, LO, 8,  10*                     Prepare engine for test cell
ACT,  20, 21, LO, 9,  11*                     Pre-induction test cell run
ACT,  21, 22*                                 Connector
ACT,  22, 23*                                 Connector
ACT,  23, 24*                                 Connector
ACT,  14, 24, , ,  34,  ,.03*                 Test cell run not required
ACT,  24, 25, , ,  35,  ,  .95*               To major repair
ACT,  30, 31, NO, 10,  12*                    QEC removal
ACT,  31, 32*                                 Connector
ACT,  32, 33*                                 Connector
ACT,  33, 34*                                 Connector
ACT,  24, 26, , , 36, ,  .05*                 To minor repair
ACT,  26, 34*                                 Connector
ACT,  34, 35, , ,  37,  , ,A1.EQ.6.0*         Check for P-6
ACT,  34, 35, , ,  38,  , ,A1.EQ.8.0*         Check for P-8
ACT,  34, 37, , ,  39,  , ,A1.EQ.408.0*       Check for P-408
ACT,  41, 42, LO, 11,  13, , ,A3.EQ.2.0*      Check for major repair
ACT,  41, 42, LO, 12,  14, , ,A3.EQ.1.0*      Check for minor repair
ACT,  42, 43, , , 40,  ,  .90*                To AWP
ACT,  43, 44*                                 Connector
ACT,  44, 45, LO, 13,  15, , ,A3.EQ.2.0*      AWP for major repair
ACT,  44, 45, LO, 14,  16, , ,A3.EQ.1.0*      AWP for minor repair
ACT,  45, 46, , ,  43,  , ,A1.EQ.6.0*         Check for P-6
ACT,  45, 46, , ,  44,  , ,A1.EQ.8.0*         Check for P-8
ACT,  45, 48, , ,  45,  , ,A1.EQ.408.0*       Check for P-408
ACT,  43, 50*                                 Connector
ACT,  50, 51, , ,  46,  , ,A1.EQ.6.0*         Check for P-6
ACT,  50, 51, , ,  47,  , ,A1.EQ.8.0*         Check for P-8
ACT,  50, 52, , ,  48,  , ,A1.EQ.408.0*       Check for P-408
ACT,  51, 88*                                 Connector
ACT,  52, 88*                                 Connector
ACT,  42, 53, , , 41,  ,.05*                  To AWM
ACT,  53, 50*                                 Connector
ACT,  53, 54*                                 Connector
ACT,  54, 55, LO, 15,  17, , ,A3.EQ.2.0*      AWM for major repair
ACT,  54, 55, LO, 16,  18, , ,A3.EQ.1.0*      AWM for minor repair
ACT,  55, 56, , ,  49,  , ,A1.EQ.6.0*         Check for P-6
ACT,  55, 56, , ,  50,  , ,A1.EQ.8.0*         Check for P-8
ACT,  55, 58, , ,  51,  , ,A1.EQ.408.0*       Check for P-408
ACT,  42, 60, , , 42,  ,  .05*                No delays in maintenance
ACT,  60, 61, LO, 17,  19, , ,A3.EQ.2.0*      Repair phase
ACT,  61, 62, LO,  18,  20*                   Build-up phase
ACT,  60, 62, LO, 19,  21, , ,A3.EQ,1.0*      Completion of minor repair
ACT,  62, 63, , ,  52,  , ,A1.EQ.6.0*         Check for P-6
ACT,  62, 63, , ,  53,  , ,A1.EQ.8.0*         Check for P-8
ACT,  62, 64, , ,  54,  , ,A1.EQ.408.0*       Check for P-408
ACT,  63, 65*                                 Connector
ACT,  64, 65*                                 Connector
ACT,  65, 66*                                 Connector
```

```
ACT, 66, 67, , , 55,  ,  .95*        Requires post-maintenance test cell run
ACT, 66, 89, , , 56,  ,  .05*        Post-maint. test cell run not required
ACT, 69, 70, LO,  23,    22*         Prepare engine for test cell run
ACT, 72, 73, LO,  20,    23*         Post-maintenance test cell run
ACT, 73, 74*                         Connector
ACT, 74, 75*                         Connector
ACT, 75, 85, , , 57,  ,  .05*        Engine not fixed
ACT, 85, 86, , , 59,  ,  .95*        Designate as minor repair
ACT, 85, 87, , , 60,  ,  .05*        Designate as major repair
ACT, 86, 34*                         Connector
ACT, 87, 34*                         Connector
ACT, 75, 89, , , 58,  ,  .95*        Engine fixed - needs QEC
ACT, 80, 81, NO,  21,    24*         QEC build-up
ACT, 81, 82*                         Connector
ACT, 82, 83*                         Connector
ACT, 83, 84, NO,  22,    25*         Transit back to user
ACT, 89,  76,,,62,,,A3.EQ.2.0*       Check for major repair
ACT, 89,  90,,,61,,,A3.EQ.1.0*       Check for minor repair
ACT, 90,  84, NO, 22, 63*            Transit back to user
*
*                  P A R A M E T E R S
*
PAR,  1,  36., 0.,120.*              Interarrival rate - unscheduled removals
PAR,  2,  68., 0.,  240.*            Interarrival rate - scheduled removals
PAR,  3,  60., 0.,  240.,    20.*    Transit to SSC
PAR,  4,  2.,  1.,  3.,  .5*         Transit to IMA
PAR,  5,  48., 10., 72., 12.*        Administrative processing
PAR,  6,  120.,  48., 240., 24.*     Transit to depot
PAR,  7,  456.,  288., 624., 60.*    Repair at depot
PAR,  8,  3.,1., 6.,  1.*            Prepare engine for test cell run
PAR,  9,  4.,  2.,     16.,    .5*   Test cell run
PAR, 10,  3.,2.,  5.,  .5*           QEC removal
PAR, 11,  48., 36.,    96.,    6.*   Teardown for major repair
PAR, 12,  12., 2.,     36.,    6.*   Initial stage of minor repair
PAR, 13,  360., 0.,  3168.,   48.*   AWP for major repair
PAR, 14,  24., 0.,     48.,    6.*   AWP for minor repair
PAR, 15,  48., 0.,     96.,   12.*   AWM for major repair
PAR, 16,  12., 0.,     36.,    6.*   AWM for minor repair
PAR, 17,  168.,  48., 336.,   48.*   Repair phase
PAR, 18,  240.,  144.,  360., 48.*   Build-up phase
PAR, 19,  24., 6.,     48.,    8.*   Completion of minor repair
PAR, 20,  4.,  2.,     16.,    .5*   Post-maintenance test cell run
PAR, 21,  8.,  4.,     16.,    1.*   QEC build-up
PAR, 22,  60., 0.,    240.,   20.*   Transit back to user
PAR, 23,  3.,  1.,     6.,     1.*   Prepare engine for test cell run
*
FIN*
*              E N D   O F   I N P U T   C O D E
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Bibliography

1. Barish, N.N. Economic Analysis for Engineering and Managerial Decision Making. New York: McGraw-Hill Book Company, 1962.

2. Bessent, Authella M. et al. A Microcomputer-Based Productivity Support System for Increasing the Managerial Efficiency of Operating Units. Technical report distributed during a presentation in LM 6.15, Logistics Decision Support Systems. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, May 1984.

3. Bird, M.M. et al. "Sales Negotiation Cost Planning for Corporate Level Sales," Journal of Marketing, 37: 7-13 (May 1973).

4. Bryson, First Lieutenant Gary C., USAF, David J. Husby, Captain, USAF, and Michael E. Webb, Captain, USAF. A Decision Support System for Acquistion of F-16 Avionics Intermediate Shop Test Sets Using the Systems Science Paradigm and Q-GERT. MS thesis, LSSR 11-82. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1982 (AD-A123 051).

5. Cherryholmes, C.H. and M.J. Shapiro. Representatives and Roll-Calls: A Computer Simulation of Voting in the Eighty-eighth Congress. New York: Bobbs-Merrill Company, Inc., 1969.

6. Connolly, Captain Edward, USAF, and Captain Charlie D. Johnson, USAF. A Prescriptive Model for Resource Allocation at the Intermediate Level Engine Facility. MS thesis, LSSR 26-81. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1981 (AD-A103 785).

7. Day, J.E. and M.P. Hottenstein. "Review of Sequencing Research," Naval Research Logistics Quarterly, 17: 11-39 (March 1970).

8. Department of the Navy. Naval Aviation Maintenance Program. OPNAV Instruction 4790.2B. Washington: Government Printing Office, 1 October 1982.

9. Department of the Navy. Gas Turbine Engine Three Degrees of Intermediate Mantenance; activity assignments for. NAVAIR Notice 4700. Washington: NavalAir Systems Command, 25 April 1983.

10. Department of the Navy. Navy Aircraft Engine Pipeline Standards. NAVAIR Instruction 13700.11. Washington: NAVAIRSYSCOM, 17 May 1974.

11. Department of the Navy. J-52 Site Consolidation Project Report. A report prepared by the Aircraft Intermediate Maintenance Support Office, Naval Air Station, Patuxent River MD, 10 July 1983.

12. Drezner, Stephen M. and Richard J. Hillestad. Logistics Models: Evolution and Future Trends, Santa Monica CA.: The Rand Corporation, March 1982.

13. Elmaghraby, Salah E. Activity Networks: Project Planning and Control by Network Models. New York: John Wiley and Sons, 1977.

14. Farrell, M.J. "The Measurement of Productive Efficiency," Journal of the Royal Statistical Society, 120: Part 3 (May 1957).

15. Faurie, Bruce R. A Q-GERT Approach to a Requisition Processing Simulation at Naval Supply Center San Diego. MS thesis, LSSR 09-80. Naval Postgraduate School, Monterey CA, September 1980 (AD-A095119).

16. Gershefski, G.W. Corporate Models: The State of the Art. Seattle Washington: University of Washington, 1970.

17. Halpern, Siegmund. The Assurances Sciences: An Introduction to Quality Control and Reliability. Englewood Cliffs NJ: Prentice-Hall, Inc., 1978.

18. Hammesfahr, R.D. Jack and Edward R. Clayton. "A Computer Simulation Model To Assist Intermodal Terminal Managers in Operations Analysis," Transportation Journal, 22: 55-68 (Summer 1983).

19. Henriksen, J.O. GPSS/H Users Manual. Wolverine Software Corporation, P.O. Box 1251, Falls Church VA 22041.

20. Hogatt, A.C. and F.E. Balderstone. Symposuim on Simulation Models: Methodology and Applications to Behavioral Sciences. Cincinnati OH: South-Western Publishing Co., 1963.

21. Hutchison, Lieutenant Commander John, USN. Personal interview. OP-514 Engine Management Branch, Office of the Chief of Naval Operations, Washington DC, 3 November 1983.

22. Keen, Peter G.W. and Michael S. Scott Morton. Decision Support Systems: An Organizational Perspective. Reading MA: Addison-Wesley Publishing Company, 1978.

23. Kresqe, D.T., and P.O. Roberts. Techniques of Transportation Planning: Systems Analysis and Simulation Models. Washington DC: Brookings Institution, 1971.

24. Landry, Lieutenant Hank, USN, Propulsion Branch Officer. Personal Interview. Propulsion Branch, Aircraft Intermediate Maintenance Department, NAS Oceana VA, 7 June 1984.

25. Lowell, James Russell. An Analysis of Air Force Avionics Test Station Utilization Using Q-GERT Modeling and Simulation. MS thesis, Air Force Institute of Techology (AU), Arizona State University, September 1980 (AD-A091 478).

26. Meir, R.C. et al. Simulation in Business and Economics. Englewood Cliffs NJ: Prentice-Hall Inc., 1969.

27. Morris, William T. "On the Art of Modeling," Management Science. 18: B707-B716 (August 1967).

28. Naval Air Systems Command. J-52 Program Overview. Pamphlet. Washington DC, 30 August 1983.

29. Naylor, T.H. and J.M. Vernon. Microeconomics and Decision Models of the Firm. New York: Harcourt Brace Jovanich, Inc., 1970.

30. Office of the Chief of Naval Operations, Department of the Navy. Memorandum of Agreement with Commanding Officer, Aircraft Intermediate Maintenance Support Office. Washington DC, 9 December 1982.

31. Pritsker, A. Alan B. Modeling and Analysis Using Q-GERT Networks (Second Edition). New York: John Wiley and Sons, 1979.

32. Pritsker, A.A.B. and W.W. Happ. "GERT: Graphical Evaluation and Review Techniques," Journal of Industrial Engineering. 17: 291-295 (May 1966).

33. Rubenstein, A.H. et al. "Some Organizational Factors Related to the Effectiveness of Management Science Groups in Industry," Management Science. 15: 26-30 (April 1967).

34. Sable, Lieutenant Colonel Ronald K., USAF. "The Deterrent Effect of Strategic Mobility," Defense Transportation Journal. 19: 42-73 (September 1980).

35. Shannon, Robert E. Systems Simulation: The Art and Science. Englewood Cliffs NJ: Prentice-Hall, 1975.

36. Schoderbek, Charles G. et al. Management Systems: Conceptual Considerations. Dallas Tx: Business Publications Inc., 1980.

37. Siegal, A.I. and J.J. Wolf. Man-Machine Simulation Models. New York: Interscience Publishers, 1969.

38. VanSickle, Lieutenant Commander John D., USN. Personal interview. NAVAIR Code 4114C4. Naval Air Systems Command, Washington DC, 3 November 1983.

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Repairs on jet engines of Naval aircraft are performed in accordance with the three-tiered concept prescribed by the Naval Aviation Maintenance Program (NAMP) - organizational, intermediate, and depot level. At the intermediate level, the entire repair cycle is referred to as the pipeline and includes time expended in transit, storage, administrative processing, actual repair, awaiting maintenance (AWM), awaiting parts (AWP), and test cell verification. Existing repair system directives specify a standard turnaround time (TAT) for engines in the repair cycle pipeline. Recent data, however, suggests that the actual TAT for the J-52 engine is almost four times the standard specified by the directive.

One approach to investigating this excessive time in the pipeline is to examine the operation of the repair system, focussing attention on the utilization of resources. The objective of this project was, therefore, to develop a computer simulation model which replicates the J-52 intermediate level repair cycle, concentrating on repair crews, workstands, and test cells as the major resources employed. The intended use of the model is as a management tool by which backlogs and delays at various points in the pipeline can be identified, thereby allowing managers to adjust or reallocate resources as required to achieve a more efficient operation and, hence, a lower TAT. A hypothetical scenario based on contrived parameters was developed in order to convert the model to code and demonstrate its application on the computer. The results of a sample simulation show that excessive repair backlogs and delays as well as inefficient resource utilization can, in fact, be identified in the output, thereby paving the way for management to experiment with different resource utilization schemes in order to achieve a lower TAT.