A GENERALIZED SIMULATION MODEL FOR A TYPICAL MEDICAL TREATMENT FACILITY OBSTETRICAL UNIT

THESIS

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The purpose of this research was to develop a decision support tool for users at Air Force Medical Treatment Facility obstetrical (OB) units. The immediate needs of the generalized simulation model contained in this research provide obstetrical wards with the capability to identify unit effectiveness as well as the ability to predict future performance. As a result of this model, decision-makers will now have access to information on system performance as well as insight into the effects of changing conditions. This model was formulated with the flexibility to be adapted to OB wards at regional and local hospitals throughout the Air Force. The generalized approach provides staff the opportunity to explore alternative policy options without detrimental effects on system performance. Options associated with patient arrival, departure and service conditions can now be fully explored. Possible nurse scheduling options are also afforded through model output.

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THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Operations Research

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Captain, USAF

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Preface

The purpose of this thesis was to develop a decision support tool for users at Air Force Medical Treatment Facility obstetrical units. The immediates needs of the generalized simulation model contained in this research provide obstetrical (OB) wards with the capability to identify unit effectiveness as well as the ability to predict future performance. As a result of this model, decision-makers will now have access to information on system performance as well as insight into the effects of changing conditions. This model was formulated with the flexibility to be adapted to OB wards at regional and local hospitals throughout the Air Force.

In performing the experimentation and writing this thesis, I have had a great deal of help from others. I am deeply indebted to my thesis advisor, Lt Col Kenneth Bauer. I could not have completed this research without the invaluable lectures on simulation. His technical wizardry quickly ended many long hours of confusion and seemingly insurmountable obstacles. I also wish to express my gratitude to Maj James Shedden, who took the thankless but necessary job of being my reader. His help and patience were greatly appreciated. Major Tim Ward also aided the effort by providing indispensable information that increased my understanding of the underlying policy and operations at OB units. As a member of the Surgeon General's office, his guidance was instrumental in providing direction for the development of this simulation model. His enthusiasm did not go unnoticed. . . it was actually contagious.

I would also like to thank the people at Wright Patterson Air Force Base (WPAFB) OB unit for answering my numerous questions. Without them, this thesis would not have been possible. The continuous help and guidance from WPAFB OB personnel gave me the understanding and insight into a system that I knew little about and provided me an opportunity to develop a credible product.

Finally, I would like to thank old and new friends who have made the AFIT experience bearable. A special note of thanks to Captains Paula Teyhen, Stan Schlack and Tim Gooley, who are now official members of the extended Stephens' clan. Last, and most of all, a special thanks to family members, Mom and Dad, and especially my wonderful sister, Sandy, who tolerated my roller-coaster ride without so much as a grumble. Your love and support have made me stronger than I ever imagined.

Annette Marie Stephens

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Abstract

The purpose of this research was to develop a decision support tool for users at Air Force Medical Treatment Facility obstetrical (OB) units. The immediate needs of the generalized simulation model contained in this research provide obstetrical wards with the capability to identify unit effectiveness as well as the ability to predict future performance. As a result of this model, decision-makers will now have access to information on system performance as well as insight into the effects of changing conditions. This model was formulated with the flexibility to be adapted to OB wards at regional and local hospitals throughout the Air Force. The generalized approach provides staff the opportunity to explore alternative policy options without detrimental effects on system performance. Options associated with patient arrival, departure and service conditions can now be fully explored. Possible nurse scheduling options are also afforded through model output.

A GENERALIZED SIMULATION MODEL FOR A TYPICAL MEDICAL TREATMENT FACILITY OBSTETRICAL UNIT

I. Introduction

General Issue

The objective of this thesis was to develop a model that simulates the operation of an obstetrical (OB) unit in a typical Air Force Military Treatment Facility (MTF). Ideally, the user would work interactively with the model to generate information specific to a unit's operation. The model was designed to be used by OB wards at regional and base hospitals to determine current resource utilization and possible areas of congestion.

Background

The Armed Services are in a period of radical transition. Drastic restructuring in the face of budget cutbacks is forcing many organizations to reevaluate their effectiveness in accomplishing the mission. Family medical care, however, faces a unique situation. Its responsibility is to provide quality health services in a time critical manner and the uniqueness of its mission, prevents consolidating duties or distributing workload. The OB unit is no exception. As such, Air Force hospitals providing obstetrical care for expectant mothers and newborn infants must find methods to maintain desired levels of service at reduced costs. The situation for the future probably won't improve. During the next five years, planned reductions will reduce the total number of active-duty military in the healthcare system by 6%. As more space becomes available, the Department of Defense (DoD) doesn't expect the demand to lessen or services to go unused. To save money, the Committee on Armed

Services suggested redirecting patient flow from costly civilian practitioners back to the military (10:27-28). The end result is the same. Military obstetrics must be able to meet the demand for services despite fiscal reductions.

To deal with fiscal shortfalls, current hospital management responds in a crisis fashion by prioritizing health care. In August 1990, hospital management at Wright Patterson Air Force Base (WPAFB) responded to inadequate funding by postponing "elective surgeries", reducing or eliminating prescription drugs, and rerouting dependents and retirees to Civilian Health and Medical Program of the Uniformed Services (CHAMPUS) (16:2). CHAMPUS, a health care program available to non-active duty beneficiaries, can be used when medical service is delayed, unavailable or unfunded. CHAMPUS frequently offers a temporary fix for many hospital units to relieve long lines. In the field of obstetrics, however, one cannot postpone or reroute care for all expectant mothers and their newborn. Yet the OB units must still cope with manpower cuts and underfunding.

DoD "runs one of the nation's largest systems of healthcare." In the contiguous United States, the Military Health Services System overseas 126 hospitals and more than 500 outpatient clinics (34), (10:27). Roughly six million beneficiaries are entitled to use these facilities (21). The demand for services by this vast number of beneficiaries far exceeds the capabilities of the military health care system. As a result, many eligible beneficiaries are referred to the more expensive CHAMPUS component for care. And, as the beneficiary population expands with the general increase in life expectancy, CHAMPUS costs spiral out of control.

In recent years, funding for CHAMPUS has skyrocketed, up from $710 million in 1980 to $3.7 billion in 1992 (11:8), (10:27). Of the funds distributed to CHAMPUS, a significant percentage is routed to OB-GYN services. Many beneficiaries opt to use CHAMPUS despite the higher out of pocket expense. The most obvious cause for beneficiaries to take this route is the long delays at some military facilities and perceptions of availability of better care (10:27). Instead of expanding care, 60 medical facilities providing OB services may be eliminated sometime in the future (34). (10:27). Even though military OB units provide less expensive medical care, external factors are forcing military obstetrics to reduce or eliminate operations. The services recognize the need for board certified OB/GYN doctors, but are unable to hire them. The prevalent attitude is that a general practitioner would be of more use, especially on the combat field, than an OB/GYN doctor (8:24). Women will always be having babies, yet services for women continue to be deemphasized. This attitude contributes to the perception of civilian obstetrical units providing better services than those on base. MTF OB units are facing a double jeopardy situation. Resources allocated for obstetrical care are being cut while units face a potential increase in patient demand.

During times of peace, the medical community finds itself administering care to fairly healthy, young service people and their dependents. The medical community notes that the nature of the population lends itself to having many children. In extreme cases at smaller hospitals, the volume of patient traffic generated by women and their newborns can run as high as 40%. As a result of these high demands for OB service, effective management of manning and resource is critical. The Surgeon General (SG), an organization responsible for maintaining the effectiveness of the military health care system, has found inconsistency in the way OB services were administered from base to base. Resource requirements for identical birthing volumes generated differences up to a factor of 2. For staffing requirements, the same birthing volume generated differences by a factor of 1.5 (34). The SG and regional and local hospitals are currently unable to account for these differences or to assess the impact of manpower and service demand fluctuations since no measurement of effectiveness for a MTF OB unit exists.

As the military continues to make the transition of downsizing its forces, medical staff in all fields are facing across-the-board reductions. Hospitals are concerned about the effects that staffing and fiscal reductions will have on daily operation and their ability to provide prompt medical service (5). This concern is justified since changes will be implemented without first identifying the impact to the MTF.

The two sources of OB care available to women (i.e., MTFs and CHAMPUS) are plagued with problems. The military ward operates inefficiently and is unable to answer basic questions dealing with maximum capacity and nurse and resource utilization. Such inefficiency may be turning away potential patients that its system could otherwise absorb. To date, no work has been completed that measures the effectiveness of a typical MTF OB unit. If such a "measuring stick" existed, the impact of changes to system operation could be easily identified. Meanwhile, the more costly CHAMPUS option continues to grow unrestricted.

Military and civilian OB units provide the same service. Both are subsets in the medical field that that specialize in the care of women during pregnancy, childbirth, and the recuperative period following delivery. However, mission and attitude are fundamentally different and generate a unique set of options for each in addressing and remedying problems. In civilian hospitals there is a marketable demand for amenities. Such demand makes these extras more costly to patients, including those using CHAMPUS. Amenities include " pink and blue wallpaper, carpet and bedside phones" to paying customers while the military offers the "no frills" approach (6). Civilian units operate on this "business concept" where profit is the primary concern, while Air Force OB units provide comparable service at minimal cost to the servicemember.

Definitions

Three different "operational systems" provide obstetrical services for women. The traditional approach, typically found in the military, operates around specific equipment set up in each room. In this system, a patient is physically moved from room to room based on a woman's stage of labor. The contemporary setting, more common in the civilian sector, offers two slight variations of the "all in one" concept.

Under this system, the woman will labor, deliver and recover within the same room. Each of the settings requires different resources.

- System 1: Exam room, labor room, delivery room, recovery room and postpartum room
- System 2: Labor/Delivery/Recovery (LDR) room and PP room
- System 3: Labor/Delivery/Recovery/Postpartum (LDRP) room

Currently, there are no existing programs that model any of these systems. As a result, the advantages of one operational system over the next cannot be thoroughly analyzed.

The OB unit, using the approach outlined in System 1, is defined by the activities occurring in 1) labor and delivery 2) postpartum and 3) antepartum wards from the time of pregnancy till six weeks after delivery. L&D's primary purpose is to provide treatment for women during labor and delivery. After delivery, care is transferred to the postpartum (PP) ward where a patient's length of stay varies, depending on the complexity of the delivery (24). Antepartum (AP) testing ranges from the time of pregnancy until delivery. Prenatal care consists of regularly scheduled tests that are performed monthly until the 36th week and then increase to weekly visits. Walk-in appointments are performed in the AP ward during all stages of pregnancy (4). After hours, emergency care is provided by Labor and Delivery (L&D).

Four institutions provide medical care to beneficiaries under the Military Health Services System. The four institutions are: medical centers, regional hospitals, local hospitals and clinics (34), (9). The range of obstetrical services, as well as operating procedures, vary at each of the four facilities.

Medical centers and regional hospitals, the two largest institutions, provide full care obstetrical service to beneficiaries. Both provide a wide range of OB services, specializing in emergency care and hard-to-treat cases. Medical centers, however, have larger facilities and as a result, can treat more patients. The third largest MTF, the local hospital, provides limited services on an outpatient basis. When inpatient care is eventually required, the unit transfers responsibility to nearby medical centers or regional hospitals. Clinics, the smallest of the institutions, only provide routine (i.e., general) care for active duty members and their dependents. Clinics do not have obstetrical units and instead offer CHAMPUS funded care if treatment isn't available at other MTFs (9).

Medical centers and clinics are unique in operation in that internal operations cannot be generalized. However, regional and local hospitals have similar infrastructures that describe a unit's response to external conditions (34). Therefore, efforts to generalize obstetrical care are much more effective only when applied to conditions at the regional and local level.

The mission of a Military Treament Facility obstetrical unit (MTFOU) is to (12):

- Provide and arrange comprehensive quality commercial health care services for pregnant women
- Provide highly specialized quality referral/outpatient health care services
- Set and sustain standards for excellence in education and training for expectant mothers
- Maintain effective health care management programs
- Provide reasonably priced, state of the art medicine and services to meet the need of pregnant mothers
- Achieve full preparedness for war and peacetime contingencies

The staff at a typical MTFOU can consist of five personnel classifications: technicians, nurse practitioners, nurses, midwives and doctors. Technicians are tasked with administrative work and additional duties which keep the unit operating efficiently. Such duties include logging pregnancy tests, scheduling appointments, coordinating labwork, chaperoning pelvic exams and taking vital signs. Nurses, unlike technicians, have an accredited degree from a four year nursing institution. Responsibilities are varied, ranging from administering drugs to providing counsel. Nurses also assess patient status, track patient recovery and administer to patient needs. Nurse practitioners, meanwhile, have a master's degree and specialize in a obstetrical care. In a role similar to that of a doctor, practitioners prescribe medication and perform all tasks up to, but not including delivery. Midwives are available at some medical centers and regional hospitals and have more education and training than nurse practioners. Their duties carry through treament and delivery of uncomplicated pregnancies. Doctors administer varying degrees of care depending on the patient's status and specialize in complicated pregnancies. Most are also OB/GYN surgeons (24), (9).

Currently, national guidelines and recommended nurse-to-patient ratios for obstetrical care are defined by the American Academy of Pediatrics (AAP) and the American College of Obstetricians and Gynecologists (ACOG) (1). These standards act as guidelines and are used to generate staffing requirements associated with different levels of patient demand.

System Overview

The system overview section generically describes how and when a pregnancy transitions from one stage to the next. It also provides a description of the type of care received and the resources required in each stage of delivery.

"Labor is divided into three stages. The first stage of labor describes the interval of time from the onset of labor until the cervix is fully dilated (10 cm). This stage is further subdivided into a latent (early) and active phase. The latent phase is characterized by slow dilation of the cervix to approximately 4 cm" (23:30). During this time, the woman is not admitted to the OB unit. The latent phase typically occurs at home and can last for several hours or days before a woman reaches the next phase of labor, the active phase. The active phase is characterized by more rapid dilation. At this time, the woman is dilated from 4-7 cm and is admitted to the unit. Admittance is based on a check-up performed in an exam room where blood pressure and similar tests are performed. As dilation increases past 7 cm, the patient is moved from the exam room to the labor room where the nurses can closely monitor the baby's activity. The patient remains in the labor room until complete dilation of the cervix is reached at 10 cm. As the infant "crowns", the patient is moved from the labor room to the delivery room. "The second stage of labor begins with complete dilation of the cervix (10 cm) and ends with delivery of the infant. This stage can be characterized by voluntary and involuntary pushing by the patient during uterine contractions to help deliver the infant. The third stage of labor is marked from the time of newborn delivery to the delivery of the placenta" (23:30-31). The patient remains in the delivery room during this time period.

Patient recovery varies depending on the type of delivery. For vaginal births, the patient is moved to the labor room for a three hour period. For unscheduled and scheduled cesarean deliveries, the woman is transferred to the recovery room for one hour. During the recovery phase, all cesarean deliveries receive care from nurses not assigned to the OB unit. After one hour, the patient is returned to the postpartum unit where care is again provided by postpartum nurses. All patient types eventually reside in the PP unit for varying lengths of recuperation. Traditionally, uncomplicated pregnancies stay for a day or two, while cesarean deliveries remain for three to five days (23:30-31), (35), (9).

Summary of Current Knowledge

According to the SG, previous analysis that targeted obstetrics identified problems. Computations for parameters, like average patient stay, were oversimplified to the point of being ineffective. Most of these computations didn't account for realistic

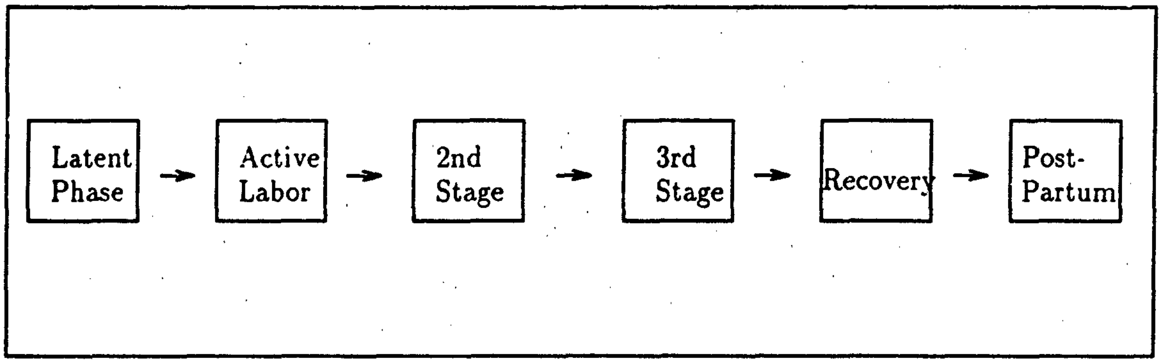


Figure 1.1. Delivery Cycle

service policies. For example, parameters related to discharge times could suggest a woman be discharged after a 36 hour stay, regardless of the time of day (i.e., patient would be released at 0100 in the morning). Such computations also assumed that all service demand was random. While this is true in a few cases, some demand can be scheduled/rescheduled for a later time. Previous efforts also failed to tailor resources to meet the demand for services (34), (27), (26). Resources are defined as staffing requirements and the types of rooms where women receive care during the different stages of pregnancy.

A text published in 1984 confirms the SG's criticism of previous efforts. Decision Making and Control for Health Administration: The Management of Quantitative Analysis is a book geared towards identifying and solving problems in the health arena. It suggests that previous works frequently, if not always, failed to implement realistic service policies (36). Several of the more recent works, which are reviewed in Chapter 2, further support the SG's statement that resources (i.e., rooms, nurses, equipment, etc.) frequently play a minor role in the analytical approach taken. Instead, resources are assumed to be able to meet the demand. Since 1984, no works have been identified that would reject this conclusion. The SG's summary of the current status of works related to obstetrical care is accurate.

Problem

The purpose of this thesis was to identify a unit's current effectiveness and to determine how OB services would react to changing requirements while maintaining the same standards of care. Until now, military OB units have operated with a fair amount of freedom. However, current fiscal cutbacks will force OB to reduce the number of on-duty nurses providing 24-hour care and may even cut the OB care provided by hospitals in half (34). These changes could have a negative impact on OB's ability to provide quality service. Today, the primary focus of hospital management is to effectively utilize existing resources. To meet this end, the model determines how OB services would degrade due to reductions in resources. The model also has the flexibility to determine how services might improve with increases in the amount of available resources. In general, the model should serve as an aid to hospital management and staff, providing decision-makers with data about the effects of changing conditions.

Scope

Three levels of obstetrical care are available to women (i.e., medical centers, regional, and local hospitals). Internal operations at medical centers are different than operations at regional and local hospitals (34), (5). One model cannot describe all three MTFOUs in a generalized format. As a result, this thesis addresses the efforts in modeling System 1. Systems 2 and 3 will not be addressed.

Using System 1 as a guideline, a single model can accurately define the process for regional and local hospitals. In this research a computer simulation model was developed that generalizes the structure of OB operations for application to a typical OB unit for these specific facilities. A MTFOU is defined by the activities occurring in labor and delivery, postpartum and antepartum wards. The OB "system" does not provide care for newborn infants. This duty is performed by the neonatal ward. The simulation model accepts patients, identifies their requirements by type of pregnancy and assigns resources based on a patient's specific needs during the course of labor, delivery, recovery and postpartum care. Resources are defined as the types of nurses and the various rooms that are used to provide care to mothers during the different stages of pregnancy. Realism is maintained by insuring that patient arrivals and departures occur during typical work days and work hours.

Patient flow is generated from six sources: vaginal births, scheduled cesarean deliveries, unscheduled cesarean deliveries, inpatient procedures, false labor patients and outpatient tests (35). Vaginal births are the most common type of pregnancy and usually account for more than 50% of patient traffic. Women typically have fewer complications and shorter recovery periods. Scheduled cesarean deliveries stem from prior health conditions of the mother or concern about delivery factors. In this case, a woman would be admitted to the PP unit and have surgery soon thereafter. Complications that occur after a woman has been admitted to the hospital and is in labor could result in an unscheduled cesarean delivery. Inpatient procedures are required for patients listed in Diagnosis Related Groups (DRG) 376 (postpartum diagnosis requiring operating room (OR) procedure), 377 (postpartum diagnosis without OR procedure), 378 (ectopic pregnancy), 383 (antepartum diagnosis with complications) and 384 (antepartum diagnosis without complications). Patients with complications or abnormal delivery signs are typical candidates that require inpatient procedures. False labor patients are women who haven't entered in labor and arrive at L&D before their condition warrants admission to the MTF. Testing for outpatients is conducted at all stages of the pregnancy prior to labor. Tests determine the overall status of the mother and fetus and are varied, ranging from diabetes checks to ultrasound testing (4).

In this model, nurses are the primary caregivers. Doctors, technicians, midwives and nurse practitioners are not included in the description of the system. Nursing staff resources for obstetrical care are generated in compliance with national guidelines and recommended nurse-patient ratios defined by ACOG (1). In order to prevent sacrificing service, these standards act as guidelines and should be maintained. As a result, nurses respond to all levels of demand and are unconstrained (35). Standards defined by AAP are not enforced since care for newborn infants is not considered in the model description.

The simulation model accepts information specific to each unit. Input and output parameters were generated based on the needs identified by the SG.

The user enters the following information (35):

- Average daily birth volume
- Percent of vaginal, scheduled and unscheduled deliveries
- Admission rate for inpatient procedures and false labor discharges
- Average daily number of outpatient tests performed
- Number of available labor, delivery, recovery, and postpartum rooms
- Discharge policies
- Patient arrival policies

This model generates the following information:

- Frequency distribution of unconstrained nursing requirements by hour of the day
- Frequency distribution of unconstrained nursing requirements by day of the week
- Facility utilization by room type
- Information on daily flow of patients
- Nursing workload generated from patients not admitted to the unit
- 95% confidence levels of staff requirements and room utilization measurements

The model also allows the user to test options on different policy alternatives. Many of the parameters that are required for model execution target areas outside of a MTF's control. The average daily birthing volume and the number of false labor patients are independent variables that are determined outside of the system. While the MTF reacts to these variables, it has no control over them. However, a unit can control policy options related to discharge and some patient arrival alternatives. These parameters include a window of release of PP patient dismissal, amount of recovery for inpatient procedures, cesarean and vaginal deliveries, and policies related to inpatient, outpatient and scheduled cesarean patient arrivals. All policy options have an immediate impact on the day-to-day operations at the system level. Variations can improve or degrade operations and need to be identified.

General Approach

No strict guidelines exist in terms of model formulation and implementation. However, previous successes frequently provide insight into successful model building. Alan Pritsker, in his book Introduction to Simulation and SLAM II, outlines ten steps for model builders. These guidelines were used as a roadmap from start to finish. Pritsker suggests that following his ten steps generates a product that is useful and can be implemented. Chapter 3 outlines each step, provides a description and documents that each step has been successfully met.

II. Literature Review

Overview

This chapter provides a review of the literature which significantly contributes to understanding the type and scope of problems affecting an OB unit. Problems typically deal with 3 issues - staffing, scheduling and resource allocation (34). Staffing issues identify how many people are required to perform a service. Scheduling issues focus on scheduling workers and address possible shift options (i.e., 8, 10, or 12 hour shifts). Allocation issues tailor resources to meet the demand for service. The majority of the works cited below deal primarily with allocation issues.

Previous Works

U.S. Army Catalog of Completed Studies. In November 1985, the Army Health Care Studies and Clinical Investigation Committee identified and consolidated a list of completed health care and dental care studies ranging from the early 1970's to 1985 (28:10). The catalog suggests that while much work was done in the medical profession, few were specific enough to apply to the OB arena. Most of the works cited concentrated on aggregate performance of the entire hospital or on narrow subjects that couldn't be modified for use in the OB unit. This was not surprising. The medical center has a variety of specialized departments and clinics, each with unique characteristics. Studies performed for these clinics (i.e., opthamology, cardiovascular, thoracic, etc.) focused on specific issues and very few, if any, could be modified to fit more than the individual unit studied.

Despite the fact that most of the studies could not be applied directly to OB, two works were of interest. In Sept 1981, a study group recommended that nursing care requirements be outlined for different OB patient classifications (28:10). Prior to the release of this effort, no strict guidelines associated with patient care existed. Intuitively, quantifying nursing requirements is critical in determining how nursing demands are affected by the type of patient requiring care. Since these results have been presented, the medical community has recognized the need of identifying nursing care requirements for different patient classifications and has since implemented standards for care as seen in the guidelines and recommendations suggested by AAP and ACOG.

In Sept 1983, a second study of interest identified scheduling options for different nursing departments (28:10). The work took a cursory look at scheduling alternatives and provided little mathematical support or justification that would support one option over another. The study group did recommend that the issue should be looked at further.

In summary, no work was identified prior to 1985 that could significantly benefit this thesis effort. More recent works, from 1985 to present, specifically targeted obstetrics. The most noteworthy studies are summarized below.

Scheduling Outpatient Services: A Linear Programming Approach. As previously mentioned, many dependents and retirees sought medical attention through CHAMPUS instead of using medical facilities. In reaction to the increasing demand for CHAMPUS services and the escalating cost of providing this care, the DoD sponsored several programs, such as PROJECT RESTORE and the Military-Civilian Health Services Partnership Program, to bring medical workload back into military hospitals and clinics (11:9). An offshoot of these initiatives developed into a concept termed catchment area management (CAM) which was tested at Reynolds Army Community Hospital (RACH) at Fort Sill, Oklahoma.

CAM "is a managed health care program which provided the hospital commander with the authority and flexibility to manage his resources and patients within his area" (11:10). Under CAM, the hospital received its direct care funding appropriations and CHAMPUS money to allocate as the hospital commander saw fit. At the time of this study, RACH provided a wide range of services for complicated obstetrical and gynecological cases to a population of more than 25,000 women (11:3). OB/GYN was one of RACHs most costly CHAMPUS services and staffing constraints at the hospital were inadequate to meet the rising demand. The hospital commander was faced with the decision of which types of patients to see and which overflow patients should be to referred to CAM. The hospital commander's decision had to balance the trade-off between the cost involved in seeing the patient on base and the cost accrued by referring the patient elsewhere. Prior to this thesis, experience, judgment and feelings guided the decisions being made (11:38).

To quantify the decision making process, Capt Darrell Hanf developed a linear programming model that identified the most cost effective appointment schedule while maintaining the quality of medical care (11:3). This was accomplished by classifying outpatients in one of sixteen categories. Patients were placed into categories based on type of care required. The goal of Hanf's efforts was to minimize CHAMPUS costs by scheduling the more costly appointments at a less costly military facility (11:17). Hanf's results generated combinations of appointments which minimized costs. However, the approach had serious drawbacks. Doctors were the only limiting resource. The "hard" resources (i.e., nurses, equipment and rooms) required in providing care to patients in military hospitals were not considered (11:62).

A Cost-Effective Method of Delivering OB Care. In 1976, efforts to save money combined with declining birth rates and a shortage of doctors forced Kenner Army Community Hospital (KACH) to close its OB ward. Several years later, CHAMPUS funds for OB care began to grow again (8:36). These increasing costs prompted KACH management to request research on alternatives for providing OB care to beneficiaries. Capt Pradeep Gidwanni was tasked to determine the best option available with particular emphasis on cost efficiency, effectiveness and patient participation (8:7).

Gidwanni performed straight cost analysis on all the options available, including "package deals" with civilian hospitals in the community. Results concluded that Kenner Army Hospital should reopen its OB facilities and provide inpatient services at the base. This optimal result was impractical because it was unrealistic for KACH to hire more OB/GYN doctors. Special pay incentives to lure OB/GYN doctors to base were denied even though OB/GYN care was inadequate. KACH recognized its need for certified OB/GYN doctors, but upper management was unsupportive. Doctors specializing in other areas were given priority (8:24). The next best alternative suggested specific combinations of hospital care within the surrounding community. KACH originally closed its OB unit intending to save money. Instead, its efforts eventually backfired and CHAMPUS became more costly than the system it was designed to replace (8:32).

Diagnosis Related Management System. In 1989 - 1990, the DoD military health care system initiated Public Law 100-180 (23:1). Simply stated, Diagnosis Related Groups were developed to identify how resources (i.e., doctors, nurses, rooms, etc.) would best be allocated. A DRG is a classification system which groups patients with similar treatment times and resource consumption patterns. "Each DRG relates a set of patient's demographic, diagnostic, and therapeutic characteristics to the hospital's resources they consume so that each DRG is differentiated only by those variables related to the patient's condition and treatment processes" (23:3). DRGs provide a means of identifying the workload different patient types generate for hospital staff. This system can also be used to define hospital costs associated with specific patient treatments. For an OB unit, there are 27 DRGs listed in the DRG Definitions Manual (354-384).

In 1990, Winn Army Community Hospital (WACH) found itself facing a similar situation KACH encountered years earlier. The costs associated with increasing demands for OB/GYN services financed by CHAMPUS continued to grow. Concern among hospital management noted that OB/GYN required the highest use of

CHAMPUS funds. In response to this enormous drain on CHAMPUS, Capt Bede Ramcharan pursued efforts that identified ways to provide more OB service on base and to reduce the costs incurred by sending patients to civilian doctors. Similar to Hanf's thesis, Ramcharan's goal was to minimize CHAMPUS costs by finding a combination of cases that could be treated at a military hospital, as well as cases that should use CHAMPUS for treatment.

Ramcharan's "case-mix" approach identified the 10 of the 27 DRGs and their associated costs related to staffing requirements. "A case or product mix concept consists of a collection of products which can be sold and a finite set of resources from which these products are made. Associated with each product is a profit contribution rate and a resource usage rate. The objective is to find that mix of products that maximizes profit, identifying the types and volumes of cases the hospital should see, ensuring that no more resources are used than what is available" (23:3). Linear programming constraints included doctor limitations and the time required to perform specific procedures. A weighted objective function recommended how much of each DRG should be performed based on limitations of the doctor (23:11). Ramcharan's approach did not account for "hard" resource requirements involved in providing care to patients.

Maternity Patient and Staff Nursing Perception Regarding Supportive Nursing Behaviors. Today, an increasing number of military hospitals must deal with budget constraints and cost effectiveness measures (10:27). In the process, some patients may feel that something "was lost" along the way and that the heavy emphasis on operating efficiently has overshadowed the "care component." To address this perceived change in attitude, Gardner and Wheeler constructed a checklist that attempted to define supportive nursing behavior (SNB). The checklist consisted of 52 questions that ranked SNB using a 7-point scale from "not supportive" to "always supportive." More broadly defined, the questions could be generalized into 10 concepts associated with patient care. Concepts included nurse availability, nurse confidence, time nurse spent with patient's family, etc. (15:86-88).

Using this checklist as a guide, Capt Teresa Ledzinski identified the differences and similiarities of military and civilian facility OB nurses' and postpartum patients' perceptions regarding SNB (15:12). Capt Ledzinski's thesis suggested that both civilian and military nurses and patients had similar ideas of "supportive nursing behavior." The military or civilian setting didn't affect the perceptions of what patient's considered to be important. The results of this study provided insight into what was most valued by obstetrical patients (15:62).

Simulation of an Alcohol/Drug Treatment Facility. Newer studies pick up where these previous efforts left off. Hamdy Taha, a professor at the University of Arkansas, performed a simulation study of a large nonprofit alcohol/drug treatment facility in northwest Arkansas. The treatment facility solicited funds from both state and federal agencies. To be competitive, it had to comply with federal directives on patient care. The treatment facility accepted a wide range of clientele and, as a result of the patient diversity, the facility's physical and financial resources were severely taxed (31:213). Professor Hamdy modeled the system using simulation. Historical data corresponding to patient behavior was transformed into distributions that moved patients through the system. Simulation proved especially helpful in identifying the tradeoffs involved in patient waiting time by varying number of beds and treatment time. Taha's results were presented to management to provide "hard data" in order to guide future decisions to manage the facility better.

Conclusion

Mathematical models can be categorized into two major groups, analytical models and simulation models. As shown, most of the works were analytical models that addressed some aspect of patient satisfaction. The two works completed by

Hanf and Ramcharan addressed the costs involved in providing obstetrical services. However, recommendations based on these approaches had serious shortcomings in that they didn't account for how physical resources would be affected by the results of their suggestions. Ledzinski's thesis was interesting in that it addressed similar concerns faced by the ACOG prior to nurse-patient ratio recommendations. Ledzinski suggested that patient care is made up of two components: medical technology and the "human factor." While the patient may have little insight into the technological aspect of care provided, the "human component" is easy to identify. And, if an MTFOU wants to satisfy the customer, this "human care component" should not be overlooked. As time has shown, ACOG finally recognized the need of establishing nurse-patient ratios and eventually outlined levels of nursing requirements, paving the way for higher patient satisfaction. Next, Taha's efforts spotlighted the benefits of using simulation as an effective tool in providing "firm" data for management. Simulation proved to be especially helpful for facilities that had to abide by specific government directives (31:213).

Summary

The problems involved in providing OB care can be addressed in a myriad of ways, each with it's own benefits and shortcomings. Providing quality care efficiently and effectively is a complicated exercise without any clear-cut or easy answers.

A MTF OB unit will continually face budgeting challenges. In dealing with these issues, hospital commanders must weigh the trade-offs involved in providing service without compromising the quality of care provided. If clinics intend to deliver the best possible service in the future, the medical profession must utilize their resources effectively. To accomplish this, hospital management should evaluate how an OB system would react to changes in resources. Simulation seems to be the most viable option for analyzing this type of problem in that it allows one to "mimic" the behavior of a real-world system.

Modeling through simulation provides insight into the performance of a system under different circumstances. Once the model accurately represents the important features of a system, the analyst varies the inputs and records the changes in the state of the system over time. Predefined measures of performance can then evaluate these changes and their overall impact on the system (22:2-6), (32:5). Decision makers may use this information to modify the current system to rectify an existing problem or to implement steps to save time and money.

III. Methodology

Introduction

The demand for simulation software is ever increasing. Public awareness of possible applications has mistakenly concentrated the primary focus to be on simulation software selection and the subsequent programming. The impression left is one of a "complicated exercise in computer programming" (14:21). In reality, the actual process of model coding is less than half of all the work involved. The emphasis should be placed on the systems analysis aspect of simulation modeling as accomplished in this thesis.

This chapter outlines the logical process that was used to model the obstetrical system as outlined in the research objective. Prisker suggests that sound simulation studies can be performed with a ten-step rudimentary problem-solving model. Figure 3.1 identifies the steps to guide the successful development of a simulation model (22:10).

Problem Formulation

In the process of building a successful model, the exact nature of the OB resource utilization problem must be determined. This integral step provides the foundation and direction for applying the process. Formulating a problem is a continual process. It can occur throughout the study due to the evolving nature of simulation (22:11). Accordingly, the problem definition can be revised as additional insights are gained.

During the early stages of formulation, misperception combined with limited information, narrowly scoped the problem. As additional insights were gained, it became apparent that more issues needed to be addressed. Many of the factors which were originally "hard-coded" into the simulation did not allow for the required flexibility and were modified to make the model more effective and user-friendly.

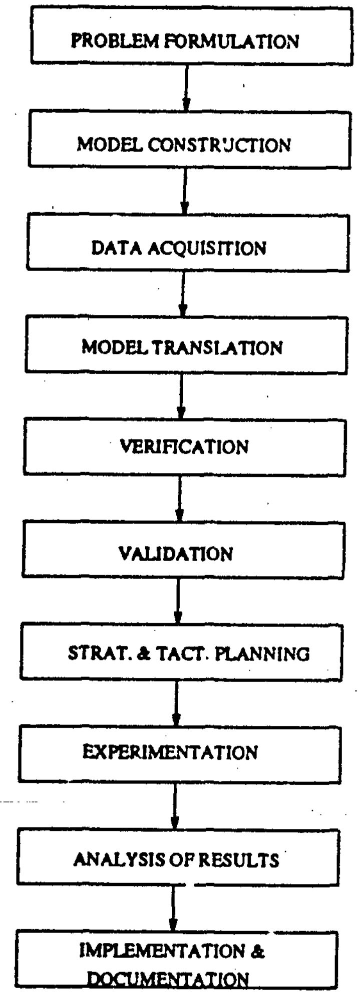


Figure 3.1. The Simulation Process

It also became evident that with two other approaches or "systems" being used in today's OB wards, this study could only address one of the "systems" and still remain manageable. As a result, additional models are to be developed in follow-on efforts that will provide all encompassing models for OB wards. This thesis provides solutions to a problem that is one third of a much larger problem.

The original problem that was formulated for this study was expanded to provide flexibility. At the same time, it was also restricted to be capable of efficiently and effectively addressing the problems encountered in System 1, the traditional system. This thesis identifies an OB unit's current effectiveness and determines how services would react to changing requirements while maintaining the same standards of care.

Model Construction

For a model to be effective, the end user must be identified. Afterwards, the level of detail and the user-friendliness can be tailored to meet the user's needs. Project objectives, data availability, real world representation, computer and programming constraints as well as inputs from "system experts all factored into the level of detail" (14:23).

Maj. Tim Ward, a member of the SG's office, provided guidance and insight into the construction of the model. His knowledge of obstetrics provided understanding and the ultimate acceptance of the model's assumptions.

After an extensive examination of the operating procedures at WPAFB's OB unit and agreement with Major Ward, the following key attributes, in addition to those outlined in the system overview section, have been identified and incorporated into a SLAM model. The sponsor's knowledge of the issues is detailed. As such, he is extensively quoted in areas where distributions, parameters and systems overview are outlined. Knowledge obtained from observing WPAFB's operation agreed with the sponsor's interpretation of the system, and as a result, have since been implemented.

As mentioned before, patients are generated from six sources. Information on the frequency of patient arrival is entered into an input file which determines interarrival times. Changes to patient arrival patterns can be made by resubmitting input parameters and running the simulation model. The six patient types are:

- Vaginal births
- False labor patients
- Unscheduled cesarean deliveries
- Scheduled cesarean deliveries
- Inpatient procedures
- Outpatient tests

Vaginal births follow the progression of labor described in the general overview section. Patients arrive according to a Poisson distribution (WPAFB patient interarrival time is 14 hours). "Early labor (or latent phase) follows an exponential distribution with a mean of 5.52 hours. The active phase of labor also follows an exponential distribution with a mean of 3.47 hours. Second stage of labor, from complete dilation to birth, has been described by a gamma distribution with a mean of .62 hours. The third stage of labor and recovery also follow the gamma distribution with means of .25 and 3.05 hours, respectively.

False labor patients follow a Poisson distribution (WPAFB interarrival time is 8 hours) and "remain on the unit for a uniformly distributed time period from one to four hours" (35). No information was available on the workload generated for the nursing staff.

To compensate for this, WPAFB nurses outlined the procedures that they follow when dealing with false labor patients. Patients receive an examination upon first entering the ward, walk for a time period (30 to 45 minutes), and then receive another dilation check. This cycle continues until time elapses and the patient leaves the ward (9). Figure 3.2 outlines the logic associated with patient traffic in L&D.

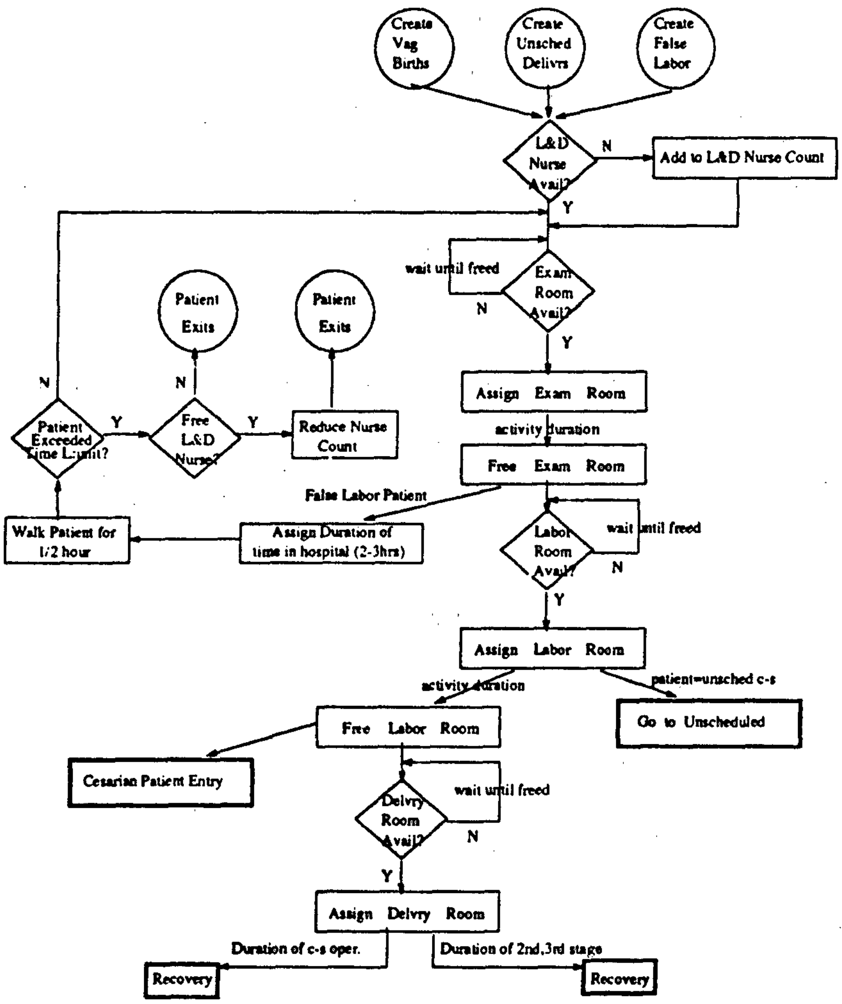


Figure 3.2. Flowchart of Patient Transitions in L&D

Unscheduled cesarean deliveries follow a Poisson distribution (WPAFB patient interarrival time is 36 hours). The majority of the deliveries are caused by dystocia or failure to progress (28%), fetal distress (10%), breech presentation (10%) and complications stemming from previous cesarean sections (35%) (35). Generalizations were ineffective in covering the remaining 17%. To compensate, the above figures were prorated to 100%. Each diagnosis deviates from an uncomplicated pregnancy in the following manner:

- Dystocia - "[Halt] the labor process (uniformly distributed) during the first three phases of labor. [Add] a two hour time delay and [proceed] with a cesarean delivery." Patient then moves to recovery and postpartum care.
- Fetal Distress - Halt labor process during the first three phases of labor. Patient then moves to recovery and postpartum care.
- Breech Presentation - Patient completes latent phase of labor and proceeds with a cesarean delivery. Patient then moves to recovery and postpartum care.
- Previous cesarean section - Patient having previous cesarean delivery has complications. Patient receives surgery then moves to recovery and postpartum care.

Figure 3.3 identifies how unscheduled cesarean patient classifications are formed. Patients are also affected by the L&D process. Transitions to and from the L&D ward are shown in Figure 3.2.

Scheduled cesarean sections follow a Poisson distribution (WPAFB patient interarrival time is 72 hours). "Patients do not experience labor [and instead] are generally [scheduled for admission] on Monday or Tuesday morning" (35). Model flexibility further allows the user to submit actual obstetrical policy dictating hours of operation and patient arrival patterns in accordance with hospital procedures. Upon admittance to the PP unit, the patient is assigned a bed. The following day, the patient receives a cesarean delivery, recovery and postpartum stay similar to that of other cesarean deliveries. Figure 3.4 describes how obstetrical systems provide services for scheduled cesarean patients. Refer to figure 3.2 for L&D system reaction to scheduled cesarean patients.

Inpatient testing is [usually available] during business hours 0800-1530, Monday through Friday. Patient arrivals are uniformly distributed during the week (WPAFB

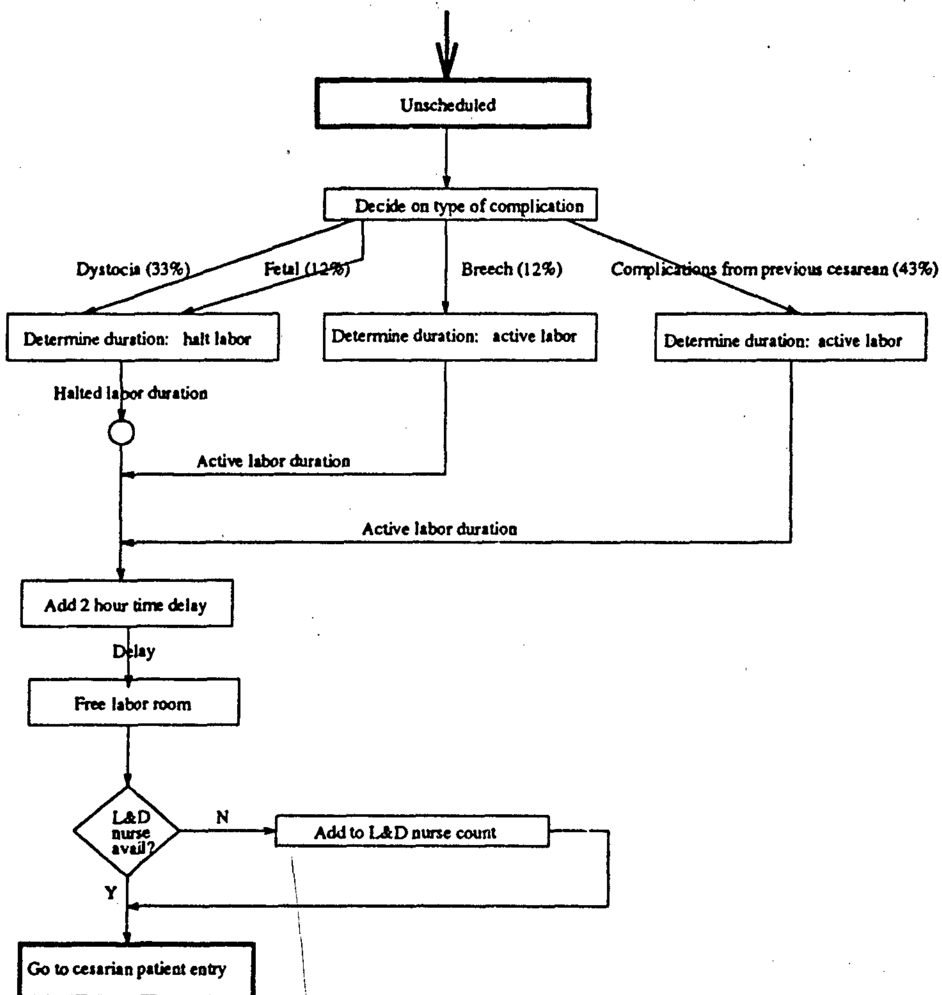


Figure 3.3. Unscheduled Cesarean Patient Flowchart

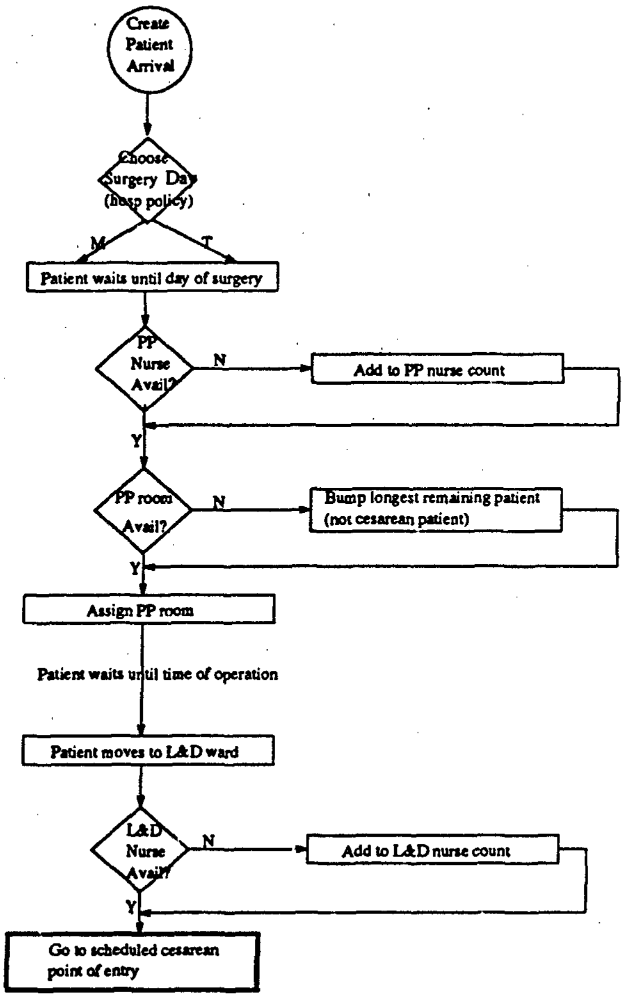


Figure 3.4. Scheduled Cesarean Patient Flowchart

patient interarrival time is 90 hours). Patient testing is also uniformly distributed and lasts for one to four hours (35). Again, inpatient testing is scheduled according to hospital policy. The program allows the user to submit hours of operation and specific days of the week when testing occurs. Figure 3.5 outlines the policies associated with inpatient procedures. Patient transition to L&D using the logic specified in Figure 3.2.

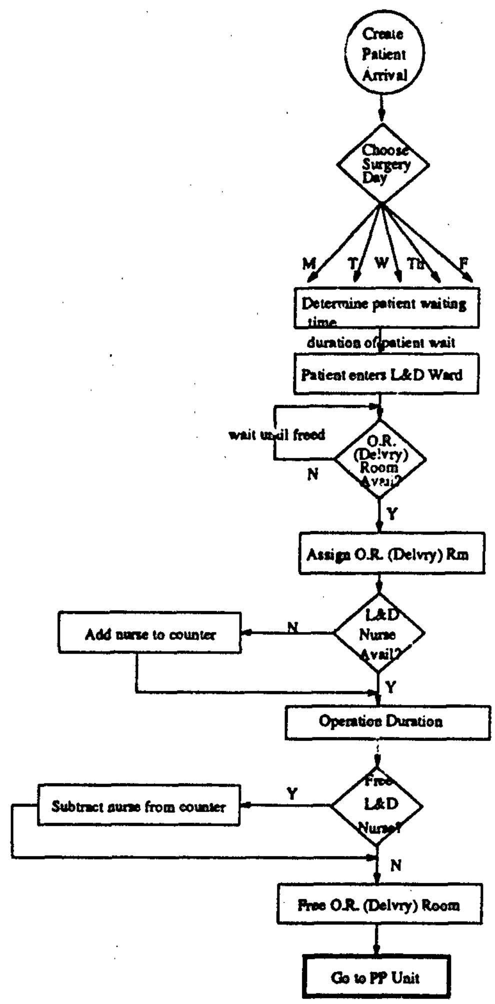


Figure 3.5. Inpatient Testing Flowchart

Outpatient testing follows a Poisson distribution (WPAFB patient interarrival time is 90 hours). "Testing is evenly distributed during business hours 0800-1530, Monday through Friday." Testing takes one to four hours to complete and is uniformly distributed (35). No information was available on the workload generated for the nursing staff. Instead, WPAFB nurses provided specific procedures used to deal with patients who received treatment but were not admitted to the ward. Hours of operation and days of patient testing can be varied. The flowchart describing outpatient testing is listed in Figure 3.6.

This model representing the traditional system fits a dynamic description. That is, it defines the way in which the "elements of the system interact to cause changes to the state of the system over time" (22:11). Sufficient staff utilization and the corresponding typical shift schedule start and stops can be obtained by simulating time in one hour blocks.

Next, a mental logic check was accomplished with the aid of the sponsor, reducing the amount of computer programming required for model construction. Verbal confirmation of model assumptions added further credibility to the modeling effort. Acceptance and implementation of the model increased since the credibility of the results is not undermined by faulty logic. This check also identified assumptions that were incorrect. Assumptions were modified or added as the need arose.

Data Collection

The SG has collected a wealth of information on patient activity. Distributions and durations have been provided that defines arrival and service times required for the majority of phases during the course of patient arrival, delivery, recovery and postpartum care. The transition from phase to phase, based on the amount of patient cervical dilation, determines a woman's location in the delivery cycle. These stages are fairly concrete and have been widely accepted by doctors and nurses as fact (7), (9). In addition, various references from well-documented sources confirm

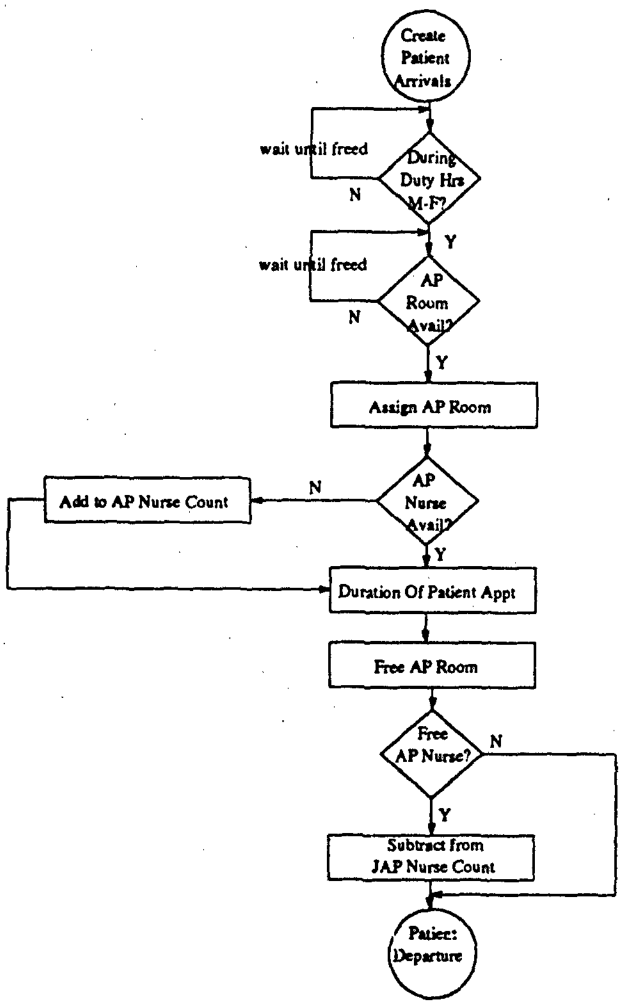


Figure 3.6. Outpatient Testing Flowchart

the parameters and distributions suggested by the SG's office (7), (29), (30), (33). One such reference is Labor and Delivery: Impact on Offspring, which cites the National Collaborative Perinatal Project (NCPP) as its source.

NCPP began collecting data in 1958 and ended with the last follow-up examinations on children in 1974. This massive collection of information had grown to exceed 2 billion items of information on more than 58,000 pregnant women (7:7). Emanuel Friedman and Raymond Noff would later use this database to develop associations between labor and delivery factors. Specifically, they were able to quantify the duration of each of the phases involved in labor and delivery for different types of pregnancies (7:54-55). As stated before, distributions and parameters generated by the SG's office and Friedman and Noff (and cited sources) were similar.

While much information was recorded in NCPP, some was not. Information on false labor patients and women arriving for testing in support of clinic activities was not available. Professional estimates and other outside sources were unable to provide further insight. Large obstetrical units in the Dayton area dismissed the problem and assumed that the nurses on hand would somehow be able to meet the demand. During peak periods, this approach frequently has nurses scrambling to provide adequate care since the impact of these patients on staff has been overlooked.

The unit at WPAFB is aware of the problem and is taking steps to identify patients in these two categeories. Nurses on shift manually document patient arrival, departure, reason for visit and action taken. However, nurses were quick to point out that, due to an oversight, some patients were not entered into the log and that heavy patient traffic made accurate record keeping difficult (9). A closer inspection of the records confirms these statements. The log could not be used to generate probabilites or distributions because of frequent and sometimes large gaps in the data. Once again, the culprit seems to be the lack of automation which would noticeably alleviate the problem. As a result of this shortcoming, the nurses at WPAFB provided estimates of the workload associated with false labor and outpatient testing and the times required to treat these patients. Many of the nurses' estimates were similar and the frequency of agreement lent support to their accuracy.

Model Translation

Model translation prepares the model for computer processing (22:11). As mentioned earlier, problems can be solved analytically or with simulation. Analytic models yield exact answers to model questions but require careful planning since minor changes may require an entirely new analysis approach. On the other hand, simulation models yield approximate answers to model questions. Modifications to plans can be easily incorporated since simulation modeling is highly adaptable to changing conditions (2). As a result, simulation was chosen because it provides answers in a format that best meets the needs of the user.

The choice of simulation software will have a large impact on project success. SLAM II was chosen as a simulation language because of unlimited modeling flexibility. FORTRAN, a general-purpose programming language, was used in combination with SLAM to increase the model's adaptability. It also aided in simplifying specific functions that SLAM would have inefficiently addressed. Additionally, FORTRAN generated input and output tables, increasing user-friendliness. SLAM diagrams that were used in translating abstract ideas into actual SLAM code are listed in Appendix A. The actual coding is listed in Appendices C and D.

SLAM coding defines the infrastructure of women moving within the system as described by activities in the L&D, AP, and PP wards. SLAM generates arrivals for each of the seven patient types, assigns durations of service activities and identifies patient location in the system. FORTRAN subroutines support the infrastructure but provide flexibility that SLAM doesn't permit. Specifically, the FORTRAN coding: 1) assigns required rooms (if available), 2) determines the number of nurses required to meet the needs of all the patients within the system 3) stores hourly/daily nursing requirements and 4) allows patients to leave the system once specific departure conditions are met.

Model Assumptions. The level of accuracy of the model and the ability to represent the system (the OB ward) is most affected by three assumptions.

- Nurses are unconstrained and can meet all service demands
- Patients wait for a specific resource (i.e., room)
- Patients can be bumped from the PP ward

Although the model treats nurses as resources, nurses are unconstrained. That is, nurses respond to all levels of patient demand. This approach was implemented to identify the number of nurses that are required for the obstetrical system using nurse-patient ratios as a guideline.

The last two assumptions were adopted to identify "bottlenecks" in the system. Under the second assumption, patients may wait for specific room types during the course of labor. Possible room shortages will be identified as well as the severity of the shortage. For example, serious considerations should be given to alternatives if patients wait 10 minutes for labor rooms and only one room is available. This position is further justified in that each room serves a specific purpose. Exam rooms cannot realistically substitute for delivery rooms. If shortages exist, nurses will "somehow make do" with the available resources. But, these "worst case scenarios" are to be avoided and, ideally, enough rooms should exist to meet the demand.

Patients may also be bumped from the PP ward if the unit is full and a new arrival needs a bed. In the past, hospitals were able to transport patients to other wards in the hospital if bedspace was limited. However, recent cutbacks will now prevent these wards from accepting OB patients due to the costs involved. The OB unit must be able to take care of all of its patients and cannot expect assistance from other wards. The model accounts for the change in hospital policy by identifying the number of patients bumped from the postpartum ward due to lack of bedspace.

Several other assumptions were made during the model development stage.

- Technicians, nurse practitioners, midwives and doctors are not considered in model development
- Patient types are generated from six sources
- Scheduled cesarean patients are generated from four sources
- No reneging in system
- No balking in system
- No clean-up times are required for rooms

File Descriptions, FORTRAN subroutines. Files were used to store patients waiting for rooms or obstetrical service. Outpatients and inpatients frequently waited in files and were only admitted to or dismissed from the system during duty hours in accordance with hospital policy. Additional information on variable definitions used throughout FORTRAN/SLAM are listed in Appendix B.

- FILE 1: Store attributes of patients while in L&D ward
- FILE 2: Store attributes of patients while in PP ward
- FILE 3: Store attributes of patients while in AP ward
- FILE 4: Store patient waiting for exam room
- FILE 5: Store patient waiting for labor room
- FILE 6: Store patient waiting for labor room
- FILE 7: Store patient waiting for recovery room
- FILE 8: Store patient waiting for postpartum room
- FILE 9: Store patient waiting for antepartum room

- FILE 10: Scheduled cesarean patient waits until Monday or Tuesday for entry to the system. Patient admitted in accordance with hospital policy.
- FILE 11: Antepartum patient admitted to system during duty hours, Monday through Friday. Patient admitted in accordance with hospital policy.
- FILE 12: Patients requiring inpatient procedures admitted to system during duty hours, Monday through Friday. Patient admitted in accordance with hospital policy.
- FILE 13: Patients stored in file for duration of postpartum stay. Patients released from system in accordance with hospital procedures (i.e., 0800-1900).

Subroutines, events and user defined functions were incorporated to assign or change patient attributes. They allowed for more flexibility and easier implementation where SLAM was restrictive. Subroutines allowed for periodic retesting of patient dismissal and insured that national guidelines of patient care were maintained. Parameters were also stored across multiple runs in order to collect statistics and generate reports.

- SUBROUTINE INTLC: Read input parameters on patient arrivals, number of room types available, and percentages of different birth types (listed in the scope section) from the file UNIT_OP. Initialize arrays. Enter hospital policies associated with patient arrival and departure conditions for all patient types.
- SUBROUTINE EVENT 1: Store scheduled cesarean patients in a file using first-in-first-out (FIFO) priority ranking. Scheduled cesarean patients wait until Monday or Tuesday before entering system.
- SUBROUTINE EVENT 2: PP ward full. Longest remaining patient in PP unit is sent to network. PP bed is made available for newest patient arrival. Bumped patients are either 1) Inpatient procedure patients 2) Patients with vaginal births. Cesarean deliveries are not bumped.

- SUBROUTINE EVENT 3: Retest patient dismissal from PP ward. Patient departs system when duration of recovery has expired and meets with hospital policy. Patient is prevented from departing the system at unrealistic hours of the day or night.
- SUBROUTINE EVENT 4: Maintain hour of the day and day of the week. Information is used to test patient dismissal. Store number of L&D, PP and AP nurses required by patients in the system every hour.
- SUBROUTINE EVENT 5: Empty.
- SUBROUTINE EVENT 6: Seize PP bed and file arrival of new patient using FIFO priority ranking.
- SUBROUTINE EVENT 7: Increment or decrement number of L&D nurses required based on the number of patients in the system. L&D nurse requirements are generated in compliance with ACOG standards and are updated each time an activity occurs.
- SUBROUTINE EVENT 8: Increment or decrement number of PP nurses required based on the number of patients in the system. PP nurse requirements are generated in compliance with ACOG standards and are updated each time an activity occurs.
- SUBROUTINE EVENT 9: Increment or decrement number of PP nurses required based on the number of patients in the system. AP nurse requirements are generated in compliance with ACOG standards and are updated each time an activity occurs.
- SUBROUTINE EVENT 10: Empty.
- SUBROUTINE EVENT 11: Update the largest number of L&D, AP and PP nurses required every hour of the day and day of the week each time an activity occurs.

- FUNCTION USERF: Determine number of patients in L&D, AP and PP wards and the associated nursing requirements required to comply with ACOG standards. Maintain highest nursing requirement for each hour of the day and day of the week.
- SUBROUTINE ALLOC: Allocate exam, labor, delivery, recovery and antepartum and postpartum rooms based on patient need. If room is not available, patient waits until room is freed.
- SUBROUTINE OUTPT: Generate statistics across simulation runs on nurse and resource requirements by hour and day of the week and other parameters of interest.

Verification

This process of verification confirms "that the translated model executes on the computer as the modeler intended" (22:12). Numerical results for pilot runs were carefully reviewed to detect remaining errors in model assumptions. The model was modified to reflect any necessary changes. The following techniques were used to debug the model (14:24).

- Modular development
- Debuggers and traces
- Structured walk-through of code
- Reasonableness of output data

Validation

The validation process checks that the desired accuracy exists between the simulation model and the real system. The performance of the simulation model determines if a reasonable representation of the system has been reached (22:24).

The following tests and evaluations were conducted until sufficient confidence was obtained. Definitions were obtained from Sargent's article on validation techniques (25:33-34).

- Degenerate Tests: Test degeneracy of model behavior by removing portions of code or by adjusting values of input parameters. Model should react as expected.
- Event Validity: Compare the "events" of occurrences of the simulation model to those of the real system. Results should be comparable.
- Extreme-Condition Tests: Test model plausibility by checking extreme and unlikely combination of levels of factors in the system. Model should bound and restrict the abnormal behavior outside of normal operating ranges.
- Face Validity: Determine if model and/or its behavior is reasonable through people knowledgeable with the system.
- Internal Validity: Determine internal stochastic variability of the model. Consistency is identified by conducting several runs and analyzing model output.
- Parameter Variability - Sensitivity Analysis: Changes to input and internal parameters of a model determine the effect upon the model and its output.
- Traces: Determine model accuracy and behavior by tracking entities as the flow through the model. Traces test the logical responses and help attain desired levels of accuracy.

There is no completely definitive approach for validating the model of the proposed system. The most definitive test of the validity of a simulation model is establishing that its performance measures as expected for proposed system configuration. If the two sets of measures compare "closely," the model of existing systems is considered valid (14:24-25).

Strategic and Tactical Planning

Strategic planning 1) explains the relationship between output responses and input variables 2) determines maximum or minimum output responses through combinations of variables set at specific levels. Answers are achieved by identifying a design of experiments which outlines how and when levels should be set (22:13). Strategic planning builds on information gained through tactical planning. For information to be useful, basic mathematical conditions must be met. Tactical planning meets mathematical conditions by identifying model weaknesses and then compensating for shortcomings by 1) identifying steady-state conditions and 2) implementing methods for reducing the variance associated with output responses (22:13). Strategic and tactical issues are discussed further in Chapter 4.

Experimentation and Analysis of Results

Experimentation describes the duration of time that is required to obtain output from computer runs outlined in the designed experiment. Next, analysis of results involves applying statistical tests to the data to identify trends, significant interactions, or other mathematical interests (22:13). The steps involved in experimentation and analysis of results are thoroughly discussed in Chapter 4.

Implementation and Documentation

Implementation refers to successfully providing a product that meets the user's needs. In this case, there were multiple users, the SG and those obstetrical units that it represents. It must be noted that the SG, not individual OB units, sought help to resolve the problems outlined in this thesis. Ultimately, the model will be provided to the SG to use as it sees fit. For implementation to be truly successful, the model should be used (as needed) by staff at obstetrical units to aid in the decision-making process.

Documentation eases the user's initial discomfort that's associated with any new product by outlining the steps involved in actually running the model, identifying and defining the variables and providing a general overview that outlines the "big picture." Flowcharts are instrumental in fostering customer happiness by providing insight into actual model operation. Instead of facing a black box that magically generates numbers, the user becomes somewhat familiar with the process and gains a basic understanding of the approach that ultimately provides solutions.

IV. Analysis and Results

Nature of Output Data

This model generates the following information:

- Frequency distribution of unconstrained nursing requirements by hour of the day
- Frequency distribution of unconstrained nursing requirements by day of the week
- Facility utilization by room type
- Information on daily flow of patients
- Nursing workload generated from patients not admitted to the unit
- 95% confidence levels of staff requirements and room utilization measurements

To generate the desired output, information was collected on variables over time. Due to the nature of the model, two problems inherent in many simulation systems were addressed (3):

- Initial Transient
- Correlated Nature of the Output

The initial transient marks the duration of time when the model starts running until the system reaches steady-state. Steady-state conditions allow for a "warm-up" period and can be identified when the characteristics of a system "remains relatively unchanged" beyond a certain point in time (3), (22:43). Steady-state or longe range conditions must be determined before confidence intervals can be generated. Welch suggests that simply deleting the values during the transient and collecting information from this point on (i.e., n_0) is the most straight-forward approach (37:290).

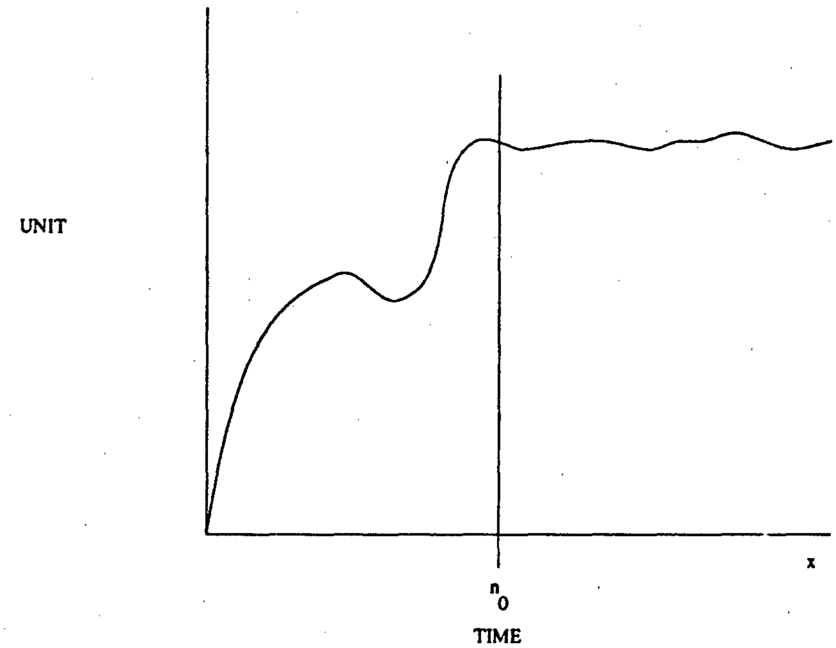


Figure 4.1. Determining Steady-state Conditions

Due to the nature of the data, typical performance measures like time in system and waiting time were correlated. For example, waiting times for the 6th and 7th customers in line should be similar since both were being affected by the same external conditions and their proximity insured the same response to system breakdowns or delays. This process was assumed to be covariance stationary.

A process is covariance stationary if (37:303):

$$E[x_i] = \mu \text{ for } i = 1, 2, \ldots \text{ and } \mu \text{ finite} \tag{4.1}$$

$$Var[x_i] = \sigma^2 \text{ for } i = 1, 2, \ldots \text{ and } \sigma^2 \text{ finite} \tag{4.2}$$

$$Cov[x_i, x_{i+j}] \text{ is independent of } i \text{ for } i = 1, 2, \ldots \tag{4.3}$$

In other words, a process is covariance stationary if "the means and variance are finite and constant and the covariance between observations depends only on the lag between them. The output of steady-state simulations may be regarded as covariance stationary or nearly so" (2).

There are two ways to handle correlated data. Welch suggests using batch means or repeated runs of a process to eliminate the correlation for a process once the mean converges to steady-state (37:294). Both methods employ different tactics to generate good estimates of the mean and variance. The method of multiple runs requires running the process m times for n units of time after the system has reached steady-state. The output is then averaged, where m runs generate independent information.

The method of batch means, in a similar manner, eliminates the correlation that exists between data by using a single long run of nonoverlapping groups. Figure 4.2 describes how groups are formed.

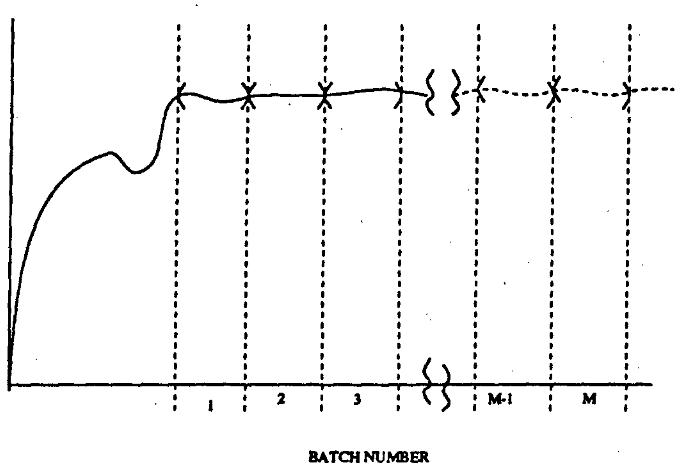


Figure 4.2. Obtaining Batch Means During Steady-State

For our purposes, there was no distinct advantage for either approach. SLAM easily collected and generated information for multiple runs and provided a distinct advantage in terms of generating output. Steady-state occurs only once in batch means and m times using multiple runs. In the end, the advantage gained in generating independent output outweighted the small efficiency obtained through batch means. Multiple runs were used to collect and generate information for confidence intervals and the other arrays of interest.

Identifying Steady-State Conditions

The model describes the activities in three separate wards for regional and local hospitals. Since operations at each will be different, no universal point in time could describe all of the possible transitions from transient to steady-state. Common sense suggested that smaller units reach steady-state earlier than larger treatment facilities since it should take less time to reach equilibrium. As a result, estimates of the transition at regional hospitals can be applied to smaller units. A large enough warm-up period should easily cover all possible situations at regional or local hospitals.

Estimates of the time required for L&D, AP and PP wards to reach equilibrium were identified using WPAFB operations as a baseline where patient activity varied in each ward. Based on specific levels of patient arrivals, steady-state conditions for the AP and L&D wards were quickly reached. The PP ward required the most time to reach steady-state, where the transition occurred at 165 hours. The early steady-state time was attributed to the relatively short length of PP stay and the high turnover rate. Duration of PP patient stay and patient arrival patterns were also varied to identify the associated times where steady-state occurred. To accomodate a "worst-case scenario," a point in time beyond these trial runs was identified and was used to signal the beginning of steady-state conditions for the generic model. Arrays were cleared and the process continued beyond this time to generate confidence intervals.

Overcoming the Problems of Correlated Data

Applying standard statistical methods to a process typically requires independence between observations. This underlying assumption is violated in that many of the target responses that SLAM provides are correlated (37:294). To overcome this obstacle, Law and Kelton suggest identifying the duration of the transient phase and the beginning of steady-state (i.e., n_0), zeroing out the arrays, and collecting information across m runs (13:551). Information within runs is averaged, where estimates of the values from the runs are uncorrelated and independent. Figure 4.3 describes the actual process (2).

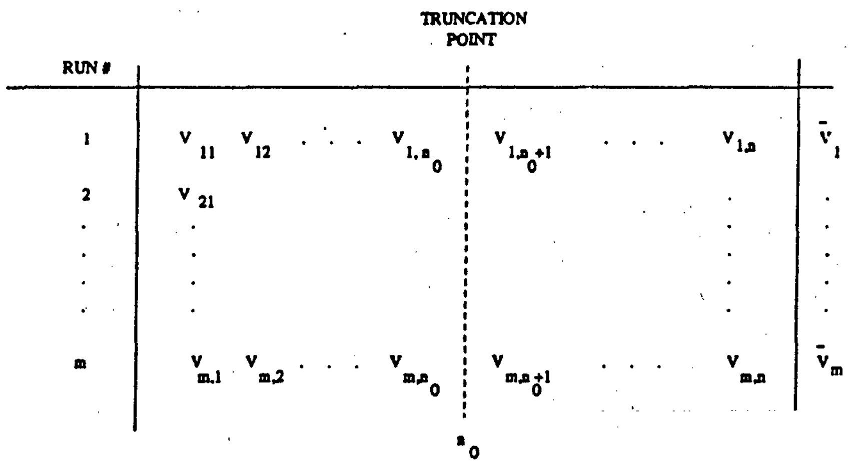


Figure 4.3. Obtaining Means for Multiple Runs

Statistical methods can then be applied to these values to generate confidence intervals for parameters of interest. Confidence intervals are generated using the following set of equations.

$$\bar{\bar{V}} \pm t_{(m-1,1-\frac{\alpha}{2})}\frac{S(\bar{V}_i)}{\sqrt{m}} \tag{4.4}$$

$$where\ \bar{\bar{V}} = \frac{\sum_{i=1}^{m} \bar{V}_i}{m} \tag{4.5}$$

$$and\ S(\bar{V}_i) = \sqrt{\frac{\sum_{i=1}^{m}(\bar{V}_i - \bar{\bar{V}})^2}{m-1}} \tag{4.6}$$

Two obvious questions are raised when output is generated.

- How many runs should be made?

- How long should the system run?

Confidence interval widths were directly affected by the responses to the questions above. Expected widths can be altered by: (37:297).

- Increasing the duration of the run time of n units
- Increasing the number of m replications

To resolve these issues, Welch suggests that it is "the best practice to keep m small, say of the order of ten, and let n be large. This minimizes any residual bias caused by the slow convergence to μ of $\{\mu_m\}$ for $n > n_0$ (37:297). These suggestions provide guidance, but other factors were also considered.

The length of n specifies the duration of the simulation run. The value of n needs to be sufficiently large to insure that estimates of the mean and variance are representative of the population. The objective in defining a length of n should clearly accomodate a "worst case scenario" where longer running times would be required to generate accurate estimates for the moments. Initially, arrays were cleared at 1000 hours and continued for 100 weeks after steady-state. The duration of n was then varied under different conditions, using shorter and longer running times as the variant. No noticeable reductions in variance were observed from increasing model run time beyond 100 weeks.

As mentioned above, no strict guidelines exist for identifying the number of replications or length of model run time. While Welch sugests that ten runs is usually sufficient, twenty or thirty replications are fairly common practice. Trial and error suggested that twenty replications, combined with a run length of 100 weeks, should be sufficient to account for all situations.

Mutiple Measures of Performance

The sponsor requested that the model generate 95% confidence intervals for activities in each of the wards. In generating multiple confidence intervals, the probability of k intervals covering their respective means is considerably less than $1-\alpha$. That is, the probability of one event occuring is different than the probability of two or more events simultaneously occurring. Bonferonni describes how probabilities are affected by multiple measures of performance (37:297).

$$P(\mu_s \in I_s \; for \; all \; s = 1, 2, ..., k) \geq 1 - \sum_{s=1}^{k} \alpha_s \tag{4.7}$$

To minimize the effect produced by multiple measures of performance, confidence intervals were subdivided into three groups. Groups were formed based on their association with a specific ward, where individual members were related measures of performance. Bonferonni's equation was then applied to the sets of related parameters associated with each group. For example, assume that six parameters defined activities in the L&D ward. Using the original α level of .05, the probability of "hooking" the true values for all of the variables at the same time was only 70%, an obvious change from the original 95%. To compensate, the original α level was reduced to generate the desired level of confidence.

Bonferonni's equation was not applied to all sets of related parameters. The number of confidence intervals for estimates of hourly/daily nursing requirements was too large and negated the opportunity to compensate for multiple measures of performance. By default, confidence levels for nurse requirements by hour and day were generated with α levels of .05.

OB Unit Output

The model was run for operations using parameters associated with system operation at WPAFB regional hospital. Output provides statistics that permits the user to evaluate the system under different conditions. Generalizations cannot be extended to other hospital obstetrical units. Each obstetrical unit is unique and reacts to the level of demand that its system encounters. Table 4.1 lists some of the more important performance measures that the model provides. Appendices E and F provide an example of output generated from a simulation run.

Table 4.1. Sample of Model Output

Parameter	Mean	Stnd Dev	Min Value	Max Value
Exam Rm Ute	0.0713	0.00116	0.0693	0.0739
Labor Rm Ute	0.6	0.0215	0.56	0.629
Avg Wait Labor Rm	10.0	0.00	0.00	0.00
Avg Wait Recvry Rm	0.0	0.00	0.00	0.00
Avg Wait Sched C-S	130	20.1	58.8	65.5
Avg Wait Outpnt	15.2	0.277	14.7	15.6
Avg Num in PP Ward	5.86	0.132	5.69	6.16
Avg Num Bumped	35.2	0.689	0.0	22.0
Avg Bmp Tm Left	-41.8	12.1	-28.8	72.0

Utilization measurements provide estimates of how frequently resources are used to meet patient demand. As expected, utilization measurements for all rooms (except PP rooms) are low since rooms are only used when a woman's location in the process of labor dictated a requirement. Although interesting, waiting times for specific room types provide more insights about system performance.

During the course of labor, a patient waits for a resource if the room is not available. Although unrealistic, this approach correctly identifies nonavailability of resources in the system. Values shown in Table 4.1 have been artificially adjusted to provide an example of a bottleneck. As shown, patients must wait 10 minutes for access to the pool of available labor rooms. The L&D unit would be alerted that additional labor rooms are required or that alternatives must compensate for the nonavailability.

SLAM output also identifies average waiting times for scheduled cesarean patients, outpatients and inpatients. OB staff can determine if the waiting times are acceptable or test alternative policies to reduce the waiting time. Table 4.1 suggests that the average waiting time for scheduled cesarean patients is 130 hours. If the

L&D unit concludes that this waiting time is unacceptable, alternative admission policies can be explored. In doing so, patient waiting times can be reduced to acceptable levels. Currently, outpatients and inpatients can be admitted any day of the week, while scheduled cesarean patients are only admitted on Monday or Tuesday.

SLAM also provides information about the number of patients who are bumped and the average amount of time that patients should have remained in the ward if bedspace was available. Table 4.1 suggests that the number of bumped patients for every 100 week period is 35.2 patients. If this number is unacceptably high, the unit would be alerted to explore options to reduce or eliminate the number of patients unable to remain in the PP unit.

The model also generates frequency distributions for hourly and daily nursing requirements. For easier viewing, the software package XFIG was used to make comparisons of nursing requirements. Actual model output is generated using Statistical Analysis Software (SAS). Figure 4.4, Figure 4.5 and Figure 4.6 identify hourly nursing requirements. Figure 4.7 identifies daily nursing requirements. These figures are useful tools in highlighting trends of nursing demands. Figures have been altered to present obvious trends. The demand for L&D nurses in the early hours of the morning shows a need for one or two nurses. Towards the late morning and early evening, the demand for L&D nurses increased, requiring that more than two nurses be on duty to meet the demand.

Daily nursing requirements are also useful in identifying trends. Figure 4.6 has been artificially set to reflect an obvious trend. As shown, nursing requirements are higher during week days and lower during the weekends.

Response Surface Methodology Applied to a MTFOU

The OB system is a complex environment that reacts to a variety of inputs. Undoubtedly, the true functional form of the equation that describes the system is unknown and complicated. The system acted as a black box, reacting or fail-

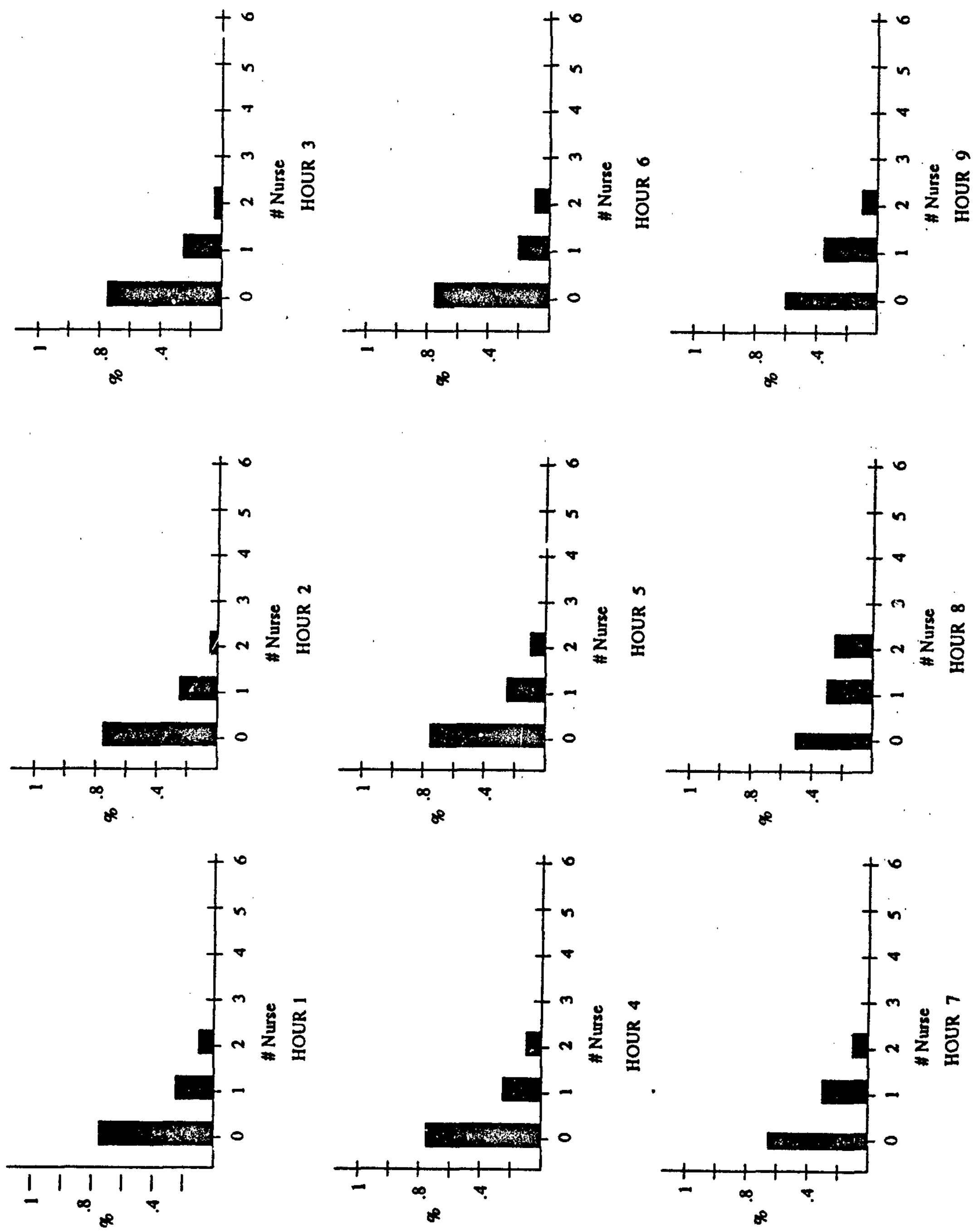


Figure 4.4. Hourly Nursing Requirements

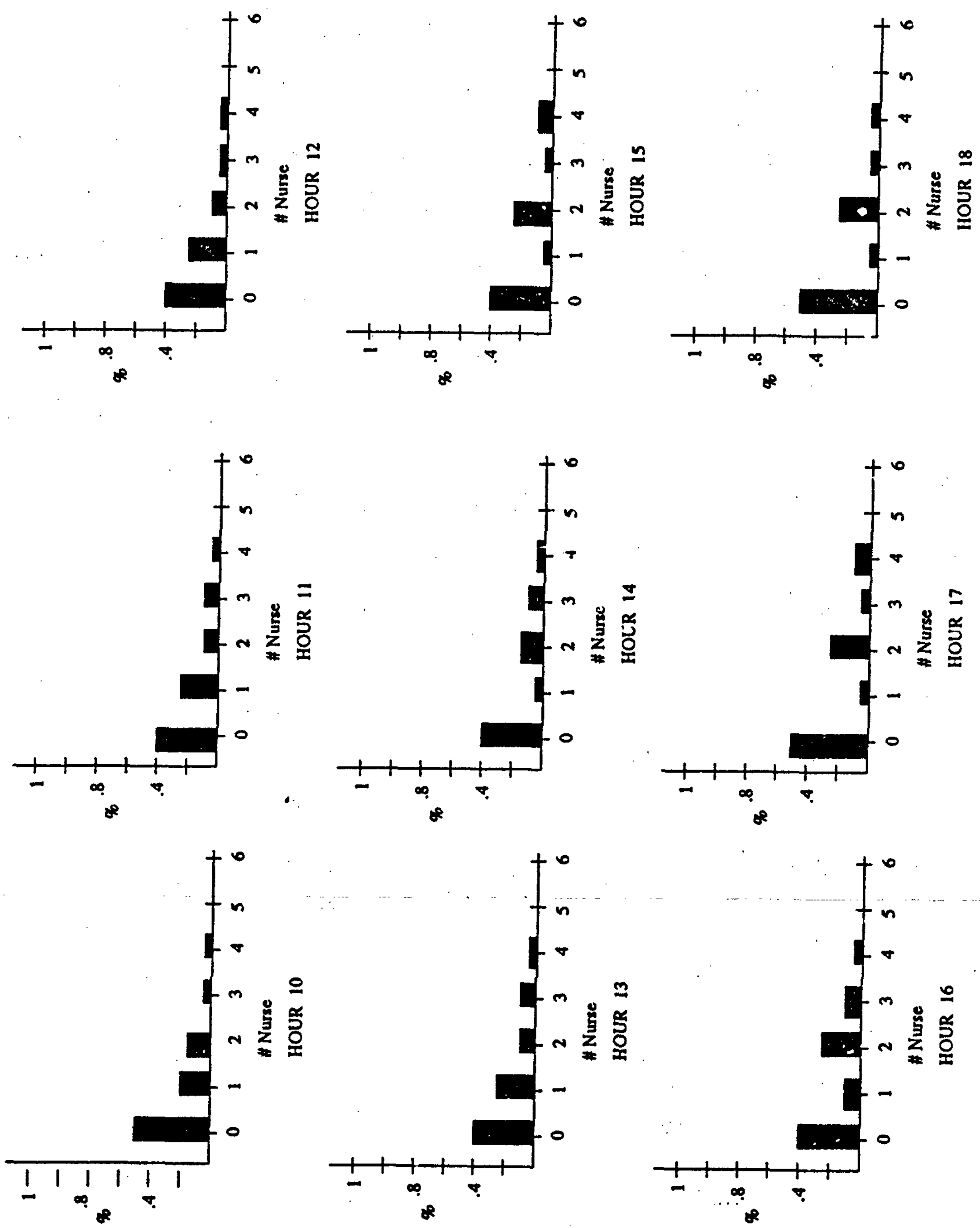


Figure 4.5. Hourly Nursing Requirements

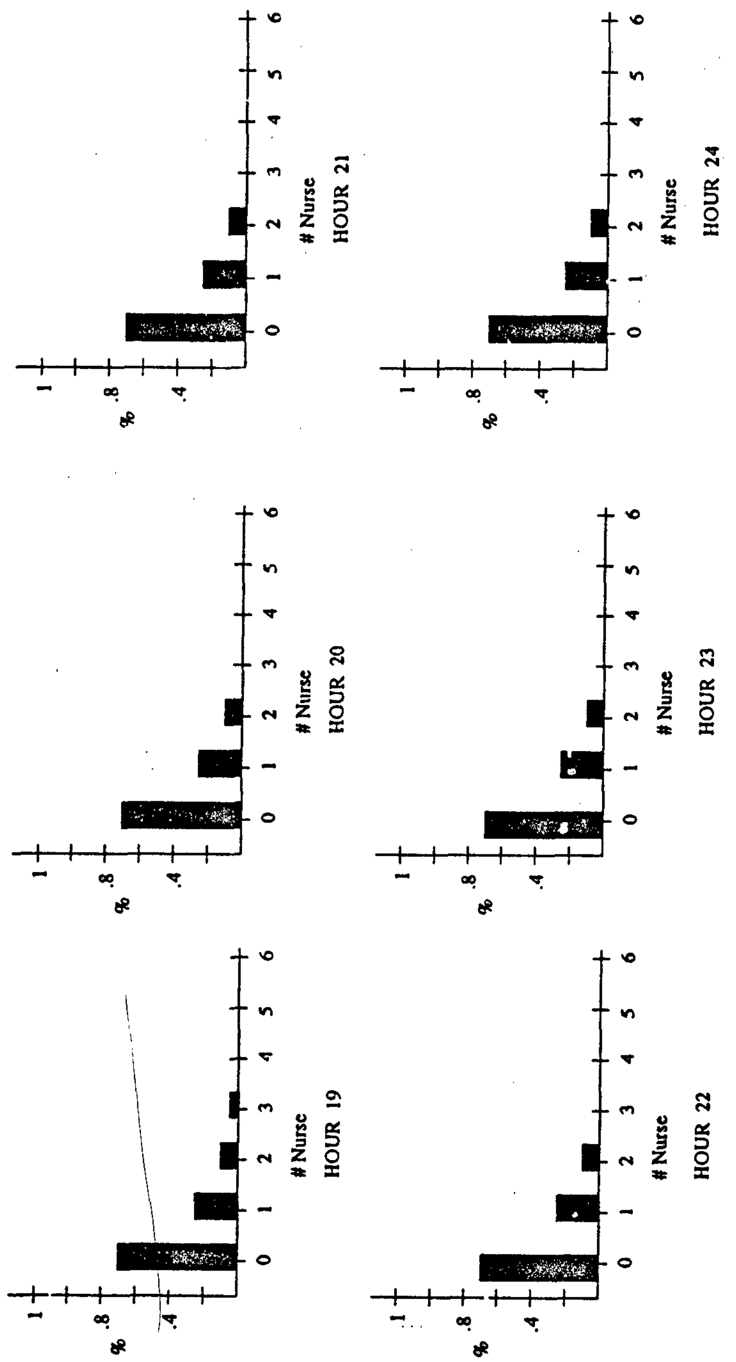


Figure 4.6. Hourly Nursing Requirements

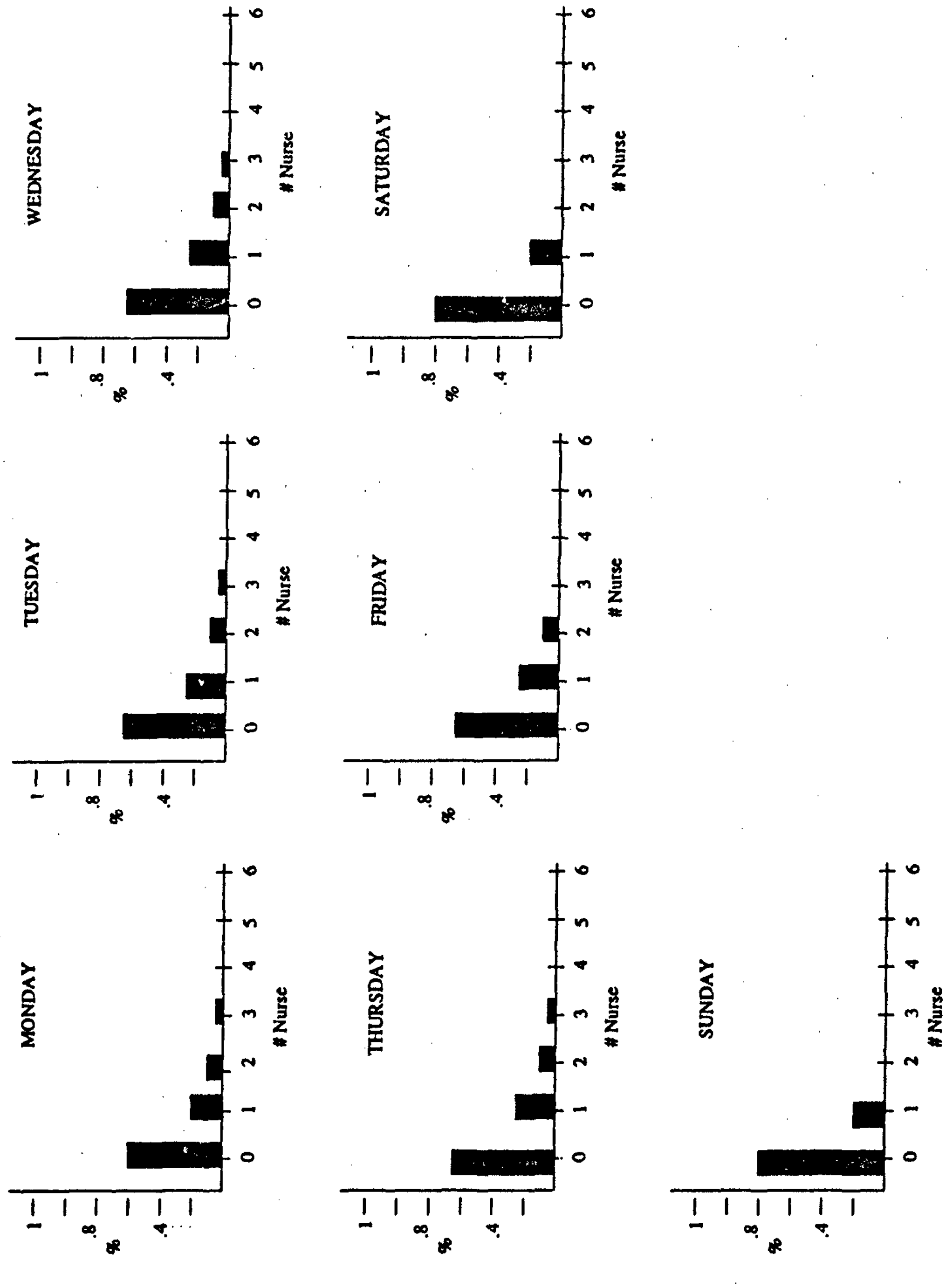


Figure 4.7. Daily Nursing Requirements

ing to react to changes in the environment. Identifiable changes in the system are either controllable or uncontrollable factors. Typical controllable factors can be hours of operation, number of servers, etc., while uncontrollable factors may involve customer demand for service. Output measures can be varied and needed to be carefully selected to insure that the correct measurement of performance monitoring system behavior is identified (19). Figure 4.8 describes the general model of a process (18:454).

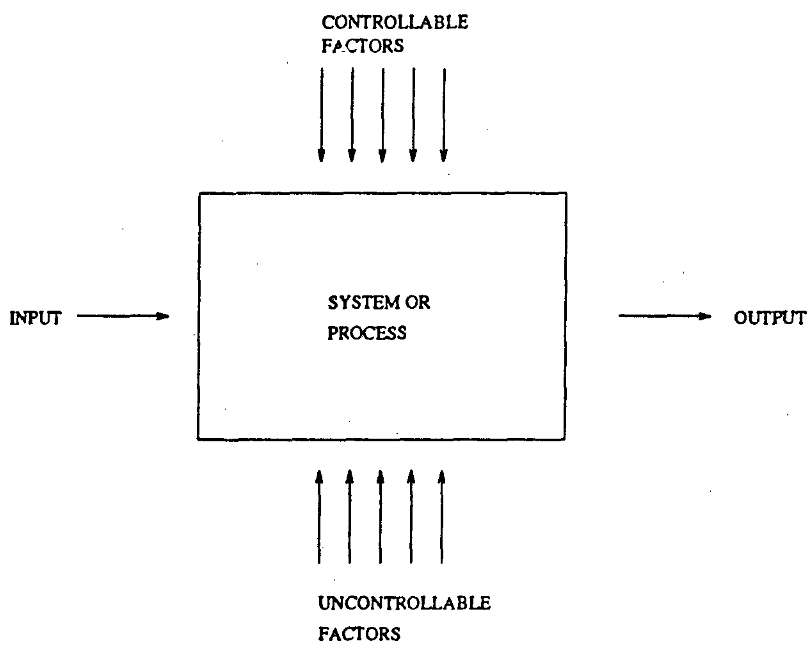


Figure 4.8. General Model of a Process

Even though the true functional form of the equation is unknown, statistical methods like Response Surface Methodology (RSM) provide mathematical techniques that can evaluate the system. These techniques include (19):

- Design of Experiments
- Regression Analysis
- Steepest Ascent

Each technique addresses a different facet for measuring system response. Experimental design combined with regression analysis was the best choice for evaluating the current system for several reasons. The strongest justification for choosing this approach over the alternatives was that it best answers the range of questions faced by an OB ward. Experimental design, used in conjunction with regression analysis, can (2):

- Determine which variables influence Y [the output response]
- Find the settings of the variables which "optimize" Y
- Find the settings of the variables which minimize the variance of Y

Model's Role in Experimental Design and Regression Analysis

The model that was developed in this thesis provides the opportunity for obstetrical units to explore how and why changes affect the behavior of its system. Previously unavailable, a unit can now provide measureable quantities whose significance can be evaluated. That is, the model provides information for use in design of experiments and ANOVA testing where the tradeoffs involved in real or hypothetical situations can be explored.

Problem Identification for use in Experimental Design and Regression Analysis

PROBLEM STATEMENT: Due to a shift in hospital policy, WPAFB's PP unit is unable to determine its ability to provide care for all of its patients. Traditionally, patients were moved outside of the ward if bedspace was limited. Budget constraints will now prevent other wards in the hospital from accepting these patients and the associated costs. In the future, the PP unit must handle all patient flow.

The variables chosen as the response should reflect how the system is truly affected and be an accurate measure of performance. As an obvious example, nurse requirements have little impact on the PP unit's ability to provide bedspace for patients. Either a bed is available or it isn't. As such, nursing parameters should not be chosen as the response variable that measures system behavior. Two possible options exist. As a first choice, some users may chose the common utilization measurement to identify system performance. However, an even better indicator would be the number of patients bumped from the ward due to lack of bedspace. Both responses were evaluated. The following discussion highlights the importance of correctly identifying a variable that measures the intended response. Choosing a less meaningful variable can lead to erroneous conclusions.

The experimental design that was chosen also provided the opportunity to determine the extent of shortcomings in previous analysis. In the past, analysis identified problems in the obstetrical field. However, previous work frequently overlooked the need to maintain realistic service policies. Patients could be released or admitted to a unit at any time of day. While this assumption seems to lead to erroneous conclusions, no statistical work has been done to confirm or deny the statement's validity. The experimental design was used to test the signficance of excluding patient arrival and departure conditions on system performance.

The controllable variables and alternative hospital policies for both responses were:

- FACTOR A:Length of stay for vaginal births (1 day: 2 days)
- FACTOR B:Length of stay for scheduled cesarean deliveries (3 days: 5 days)
- FACTOR C:Length of stay for inpatient procedures (1 day: 2 days)
- FACTOR D:Hours of release for all patient types (0800-1800: all hours)

Options were included as factors only if they could realistically be implemented. Postpartum beds were not considered to be a controllable factor and were not evaluated. WPAFB is unable to expand the postpartum ward and evaluating this option serves no practical purpose. As a reminder, nurses act as unconstrained resources and respond to all levels of patient demand.

Experimental Design, Regression Analysis Approach

Experimental design is frequently used to identify variables that influence an output response. Regression analysis further provides an opportunity to evaluate the variance associated with terms that potentially influence system behavior. In this case, WPAFB's OB unit wanted to measure their ability to provide care for all PP patients. Through experimental design, purposeful changes generating output responses were used to test the system at different levels. Statistical methods were then used to determine the significance of these controllable factors (19).

Four controllable factors, each with two levels, required evaluation. Figure 4.14 describes how the levels of the controllable factors were tested.

A	B	C	D
-	-	-	-
+	-	-	-
-	+	-	-
+	+	-	-
-	-	+	-
+	-	+	-
-	+	+	-
+	+	+	-
-	-	-	+
+	-	-	+
-	+	-	+
+	+	-	+
-	-	+	+
+	-	+	+
-	+	+	+
+	+	+	+

+ CONTROLLABLE FACTOR AT HIGH VALUE
- CONTROLLABLE FACTOR AT LOW VALUE

A - LENGTH OF VAGINAL BIRTH STAY   C - LENGTH OF INPATIENT STAY
B - LENGTH OF CESAREAN SECTION STAY   D - HOURS OF OPERATION

Figure 4.9 Experimental Design with Four Factors

At a minimum, a resolution IV design was required to identify the four main effects and all two-way interactions. The resolution of a design determines the level of confounding that takes place between variables. Specifically, a resolution IV design insures that "no main effects are aliased with any other main effects or with any two-factor interactions, however, two-factor interactions are aliased with each other" (19). In this case, a resolution IV design required eight runs while a full factorial design involved only 16 runs and identified all interactions. As a result of the increase in explanatory power, a full factorial design was conducted and then analyzed.

In generating output, the sponsor wanted to identify parameters with 95% confidence (i.e., $\alpha = .05$). For the estimates to be useful, the power of the test was also considered. The power of a test identifies Type II errors which are essential in "evaluating the performance of a test." In mathematical jargon, a Type II error is the probability of accepting the null hypothesis when it should be rejected. Ideally, the user would always want the lowest α and β errors. Sample sizes and replications factor into the trade-offs involved in detecting or failing to detect false assumptions (17:471). Accordingly, the experimental design required 20 replications to generate results with power= .7 (20:1151). Differences were identified within two standard deviations.

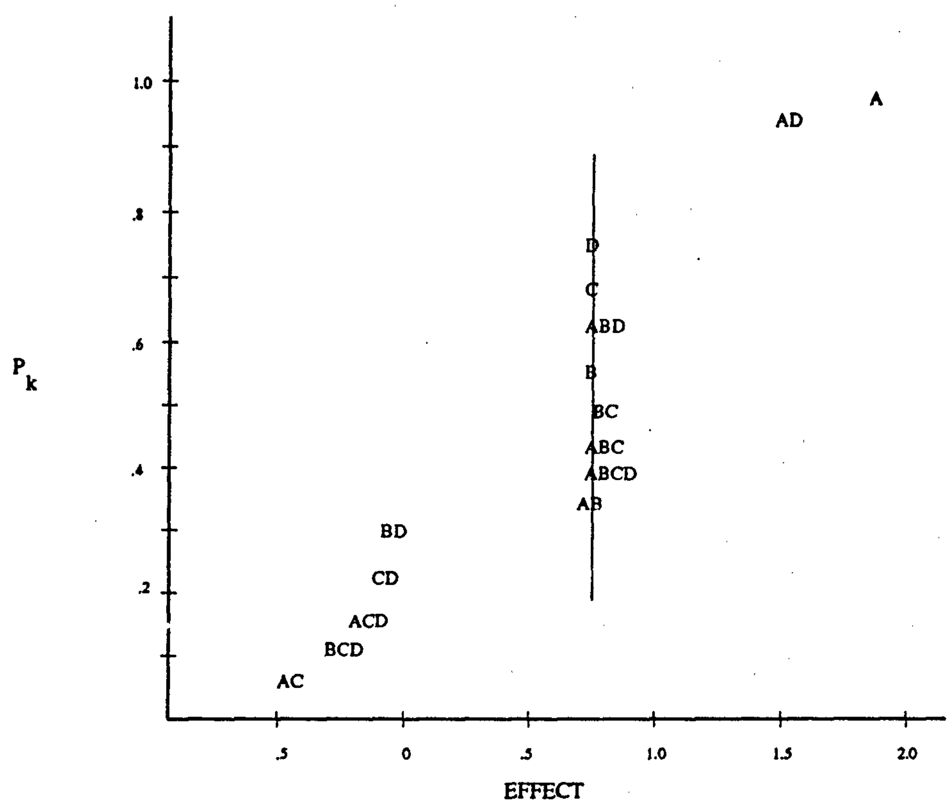
Experimental Design Results

The full factorial design estimated all interactions and required 2^4 or 16 runs to be made for each of the 20 replications. Every possible combination of the factor levels was explored and tested for significance. Using 16 runs, the designed experiment tested the four main effects and all interactions. The effects associated with each factor were then sorted, lowest to highest, and charted on a normal probability plot. If there were no significant effects (i.e., factors), the points would fall along a straight line. If the main effects were significant, the points should deviate from the line. Figure 4.10 and Figure 4.11 plot the effects of pospartum bed utilization and average number of patients bumped from the system.

Figure 4.10 only identified main effect A as being significant. Since the vast majority of L&D patients deliver vaginally, reasoning would conclude that this group would contribute the most towards the utilization measurement. Patients requiring other types of care made up a smaller percentage of overall patient flow and had significantly less impact on system performance. The two-way interaction terms AD, BD, and CD were also significant. Again, this result made sense in that hospital dismissal policy for all patient types affected how much resources were used in the system. As patients were prevented from leaving the system at unrealistic hours, utilization readings responded accordingly. Longer stays in the postpartum ward generated higher postpartum bed utilization. The significance of the interaction between length of stay for vaginal births and length of stay for inpatient procedures (ie., AC) was also apparent. Patient interaction was significant due to the number of patients admitted to the system and their contribution to overall postpartum bed utilization.

Figure 4.11 shows that all main effects (i.e., A, B, C, D), several two-way interactions (i.e., AB, BC, AC) and one three-way interaction (i.e., ABC) significantly contributed to the average number of patients bumped from the system. Logically, all patient types (except cesarean patients) contributed to the number of patients bumped from the ward. Through model construction, cesarean patients could not be bumped from the system and therefore could not contribute to the overall figure. The complications associated with surgery prevented these patient types from being forceably removed from the system.

The interaction term for length of stay associated with vaginal births and cesarean and inpatient stay (i.e., AB, AC) also contributed to the overall number of bumped patients. Vaginal births were the largest group of patients requiring care. As such, these births had the most impact on the ability of the system to provide care for all patients and made up the largest percentage of patients who were forceably removed from the system. As cesarean and inpatient stays increased,



RESPONSE: RESOURCE UTILIZATION
FACTOR A: VAGINAL BIRTH LENGTH OF STAY
FACTOR B: CESAREAN LENGTH OF STAY
FACTOR C: INPATIENT LENGTH OF STAY
FACTOR D: HOURS OF RELEASE POLICY

Figure 4.10. Normal Probability Plot for Resource Utilization Measurement

more vaginal birth patients were bumped. Length of stay associated with scheduled cesarean patients and inpatients (i.e., AC) also affected system behavior. Patients falling within these categories incur the longest recovery periods. The system was less able to provide care for all patient types as length of stay for inpatients and cesarean patients increased.

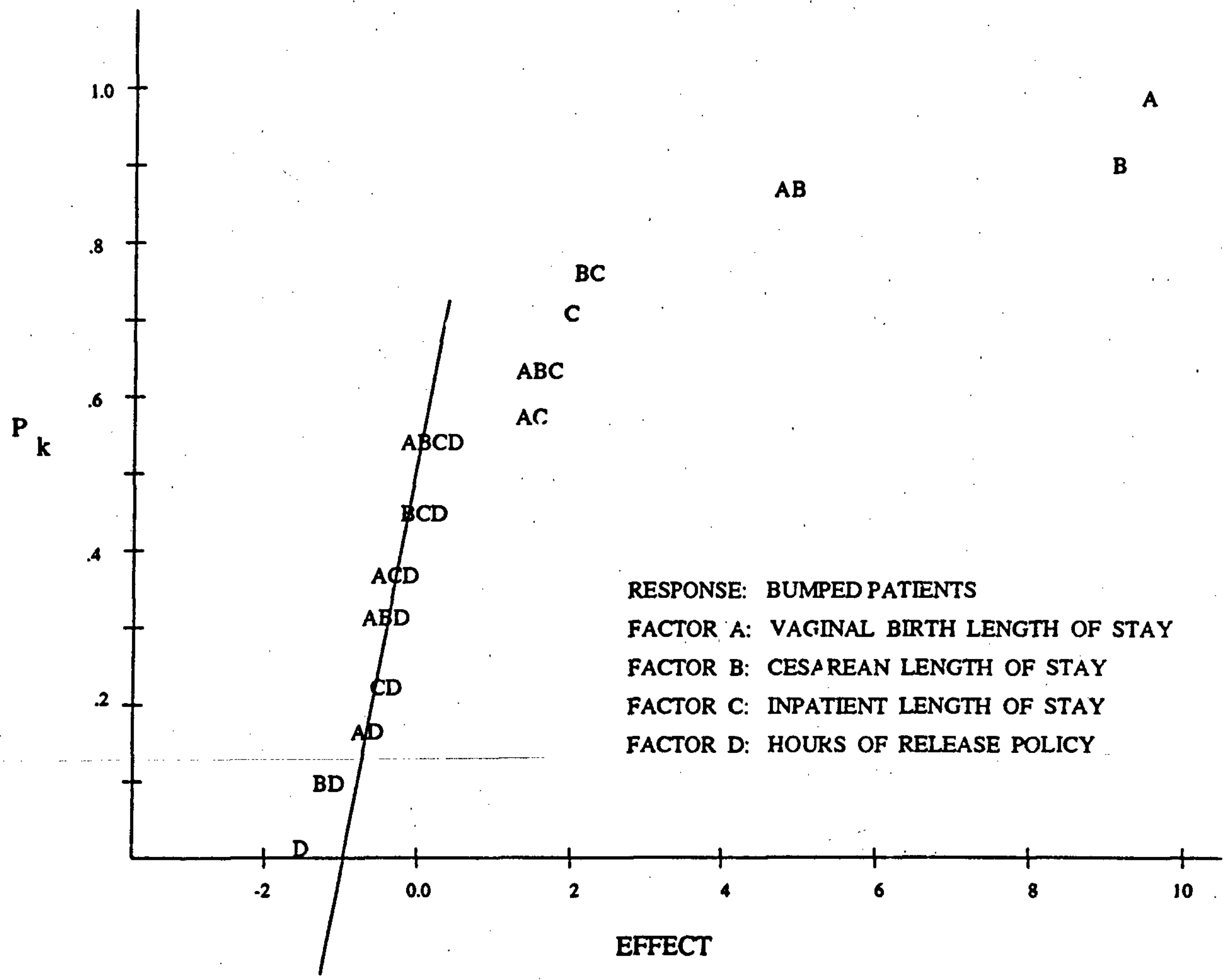


Figure 4.11. Normal Probability Plot for Patients Bumped From PP Ward

At this point, each probability plot identified different sets of terms as being signficant. Obviously, different conclusions could be reached depending on which plot was chosen. At this point, it was decided that the number of patients bumped from the system was more reflective of the response to be measured. The resource utilization measurement for the PP ward was not an accurate response variable for several reasons. While useful in identifying factors which contributed the most towards increased resource usage, it was *not* a good indicator of periods of excessive strain associated with patient demand. The experiment was conducted to identify what actions a PP unit could take to reduce the amount of patients that its system could not accomodate. As such, the response variable should measure system performance when the PP ward was severly taxed and unable to provide service. During these times, an average measure of performance was not useful for gauging extreme conditions. Further analysis was conducted using bumped patients as the response variable measuring a postpartum wards ability to provide care for all patients.

On average, the postpartum ward can provide care for patients. The signficance of vaginal births (i.e., Factor A) supports this argument in that these patients make up the majority of patient flow for the ward. However, this was not the objective of the experimental design.

Regression Analysis. Probability plots were useful in identifying significant variables. However, these plots were unable to discern the level of significance of terms that deviated from the line or how the system should operate to improve performance. Regression analysis was used to address both weaknesses by identifying levels of significance as well as determining what levels factors should operate at to achieve peak performance.

The software package SAS generated a linear regression equation. Table 4.2 identifies that the equation was significant at the $\alpha = .0001$ level. Significant effects were identified and are listed in Table 4.3. All parameters were previously identified using normal probability plots.

Table 4.2. SAS Output

Source	DF	Sum of	Mean	F Value	$Pr > F$
Model	15	16797.4969	1119.8331	55.60	0.0001
Error	304	6122.8500	20.1410		
Corr Total	319	22920.3469			
	R-Square	C.V.	Root MSE		BUMP
	.7329	57.7450	4.4879		7.7719

Table 4.3. Significant Variables provided by ANOVA

Parameter	Estimate	T for H0: Parm=0	$Pr > \|T\|$
Vag Births	4.6906	18.70	0.0001
Cesarean	4.5719	18.22	0.0001
Inpatient	0.9719	3.87	0.0001
Hrs of Release	-0.7594	-3.03	0.0027
AB	2.4156	9.63	0.0001
AC	0.4906	1.956	0.0514
BC	1.0594	4.22	0.0001
BD	-0.5094	-2.03	0.0432
ABC	0.5781	2.30	0.0219

As a next step, two-way and three-way interaction plots were generated for significant terms. These plots, used in conjunction with the signs of significant coefficient terms shown in table 4.3, provided information about how combinations of variables affected system performance. Figure 4.12 identifies the interaction terms AD, AC, BC and BD as having an interaction.

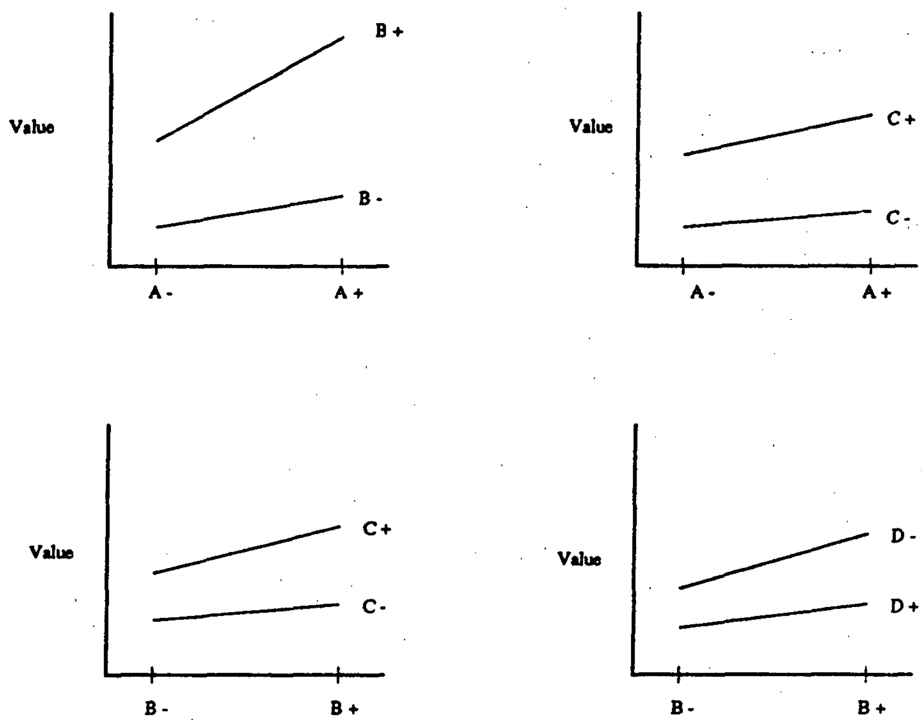
The term AB represents the relationship between length of stay for vaginal births and ceserean patients. To minimize the number of patients bumped from the system, the hospital should implement shorter lengths for stay for both patient types.

The term AC represents the relationship between length of stay for vaginal births and inpatients. To minimize the number of patients bumped from the system, the hospital should implement shorter lengths for stay for both patient types.

The term BC represents the relationship between length of stay for cesarean patients and inpatients. To minimize the number of patients bumped from the system, the hospital should implement shorter lengths for stay for both patient types.

The term BD represents the relationship between length of stay for cesarean patients and hospital policy for releasing patients from the system. To minimize the number of patients bumped from the system, the hospital should implement shorter lengths fo stay for cesarean patients and permit patients to depart the system at all hours.

The term ABC represents the relationship between length of stay for vaginal births, cesarean patients and inpatients. To minimize the number of patients bumped from the system, the hospital should implement shorter lengths fo stay for all patient types. The results suggested in Figure 4.13 didn't contradict previous factor settings that would minimize the response variable.



RESPONSE: BUMPED PATIENTS
FACTOR A: VAGINAL BIRTH LENGTH OF STAY
FACTOR B: CESAREAN LENGTH OF STAY
FACTOR C: INPATIENT LENGTH OF STAY
FACTOR D: HOURS OF RELEASE POLICY

Figure 4.12. Two-Way Interaction Plots for Patients Bumped From PP Ward

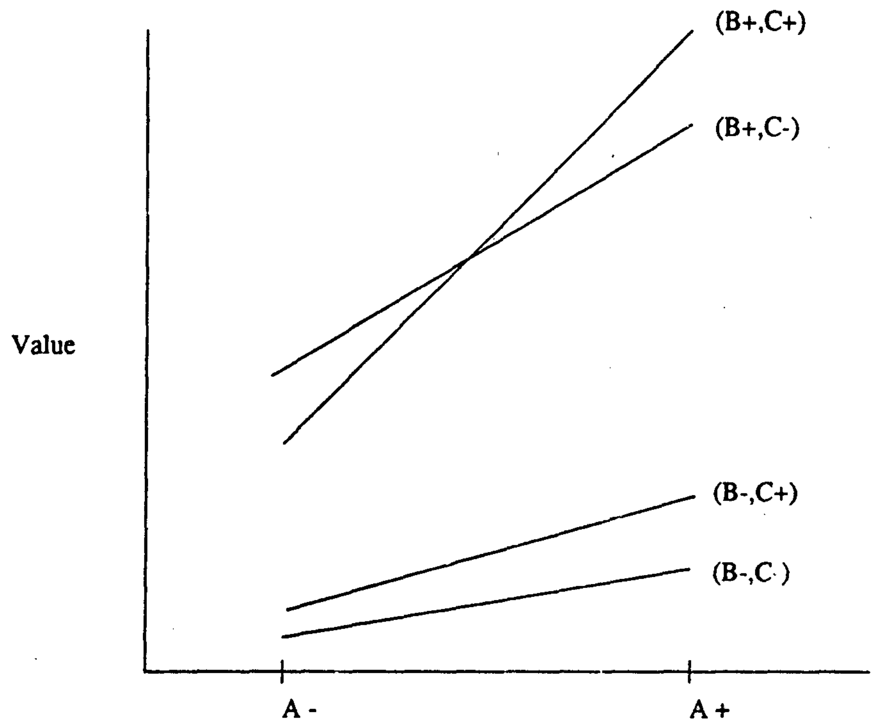


Figure 4.13. Three-Way Interaction Plot for Patients Bumped From PP Ward

Experimental Design Conclusions

The purpose of this experimental design was to identify the statistical significance of factors related to the OB unit's ability at WPAFB to provide care for all of its patients. Two responses, postpartum utilization and bumped patients, measured the unit's ability. Utilization measurements are typically the measurement of choice for system performance. This practice should not preclude other variables from being considered. As shown, the utilization measurement should not have been selected to as the response variable. Instead, the number of bumped patients more accurately reflected which factors contributed to the conditions of the system which caused patients to be bumped.

Results also showed that hospital policies associated with patient dismissal strongly influenced the number of patients that were bumped from the system. While intuitively obvious, these results confirm that erroneous conclusions may have been reached by omitting these variables in previous model formulations. Patient arrival and dismissal policy had significant effects on system performance and should not be dismissed. The results further suggest that a unit can control certain aspects of system behavior by modifying current hospital policy.

Experimental design further demonstrated the strength of the model in evaluating alternative hospital policies and how these alternatives both negatively and positively affected system performance. Once solutions were reached, generalizations could not be extended to other hospital operating procedures. Each obstetrical unit is unique and reacts to the level of demand that its system encounters.

A	B	C	D
-	-	-	-
+	-	-	-
-	+	-	-
+	+	-	-
-	-	+	-
+	-	+	-
-	+	+	-
+	+	+	-
-	-	-	+
+	-	-	+
-	+	-	+
+	+	-	+
-	-	+	+
+	-	+	+
-	+	+	+
+	+	+	+

\+ CONTROLLABLE FACTOR AT HIGH VALUE

\- CONTROLLABLE FACTOR AT LOW VALUE

A = LENGTH OF VAGINAL BIRTH STAY
B = LENGTH OF CESAREAN SECTION STAY
C = LENGTH OF INPATIENT STAY
D = HOURS OF OPERATION

Figure 4.14. Experimental Design with Four Factors

V. *Recommendations and Conclusions*

Synopsis of OB Systems

This thesis addressed the obstetrical system under the traditional setting. In this system, a patient is moved from room to room based on the woman's stage of labor. Alternative decisions dealing with system behavior can be weighed using this model as a guide. Patient admission and discharge policies can be compared using impact to system operations as a benchmark. While the model provides the decision makers with tools previously unavailable, it does not allow for comparison with the other two contemporary obstetrical systems. These newer approaches combine the "all-in-one" concept where a woman can labor, deliver and recover all in the same room. LDR and LDRP rooms are uncommon in the military. This should not prevent decision-makers from viewing LDR and LDRP rooms as possible alternatives if such systems are more efficient. Since only one model exists, comparisons cannot be made.

At first glance, the two alternative approaches seem to require fewer nurses and generate higher room utilization measurements. Under these systems nurses serve multiple purposes and can move to meet the demand. This differs from the tradional situation where the three different wards operate independently. Nurse mobility is limited with system 1 in that nurses remain in their assigned ward. As a result, some units may be overstaffed while others are severly taxed. The newer approaches have nurses providing all of the specialized services that were previously provided in different wards.

Areas of Future Work

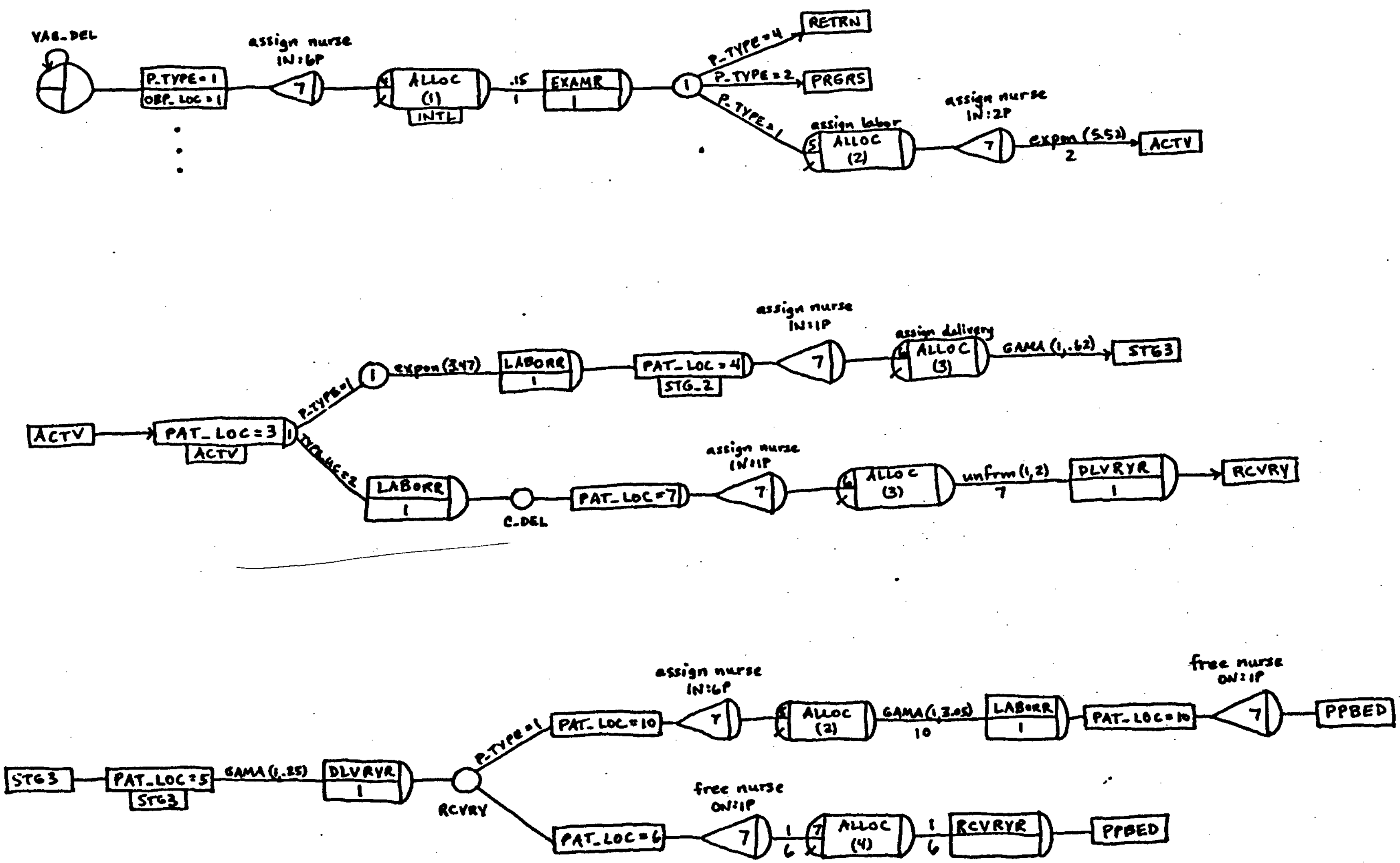
The current model can be improved by increasing the user-friendliness aspect of running the program. Improvements can be obtained by reducing the number of prompts which require the user to submit information. SLAM ouput tables can be difficult to read and should be replaced. Currently, Stastistical Analysis Support (SAS) generates frequency distributions for hourly and daily nursing requirements. SAS is a bulky package and requires high powered personal computers (PCs) to be effective. Smaller PC packages that provide good visual comparisons should be identified and replace SAS.

Further efforts should provide simulation models that outline operations using LDR and LDRP rooms. From this point, estimates of a ward's ability to meet demand could then be compared under each of the different systems. Estimates could also be provided outlining the bottlenecks to the proposed system.

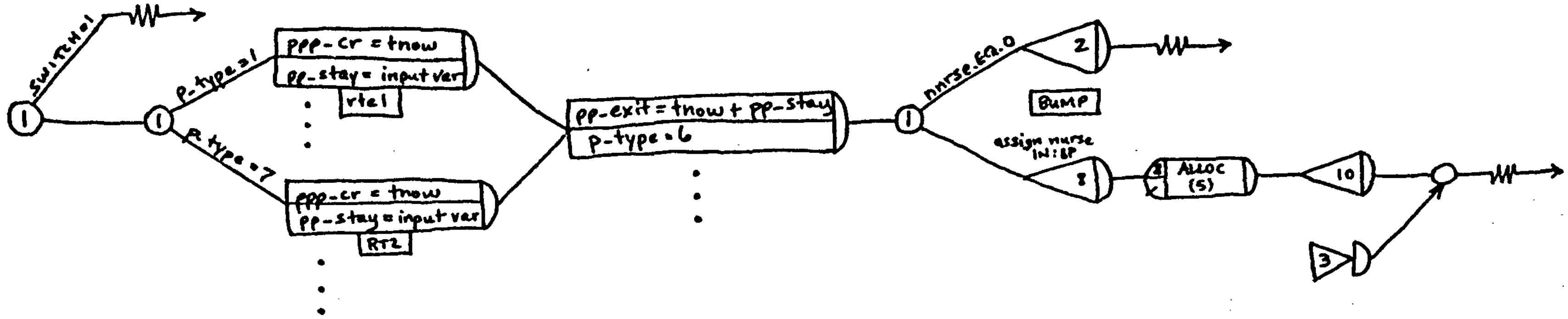
The SG suspected that OB units needed a tool to help decision-makers weigh alternatives and identify the impact of proposed changes. The idea behind developing the model was to provide a tool to help OB units operate more effectively and efficiently. This model will be truly successful <u>if</u> it is applied as intended <u>and</u> provided to obstetrical units at regional and local hospitals.

L + D

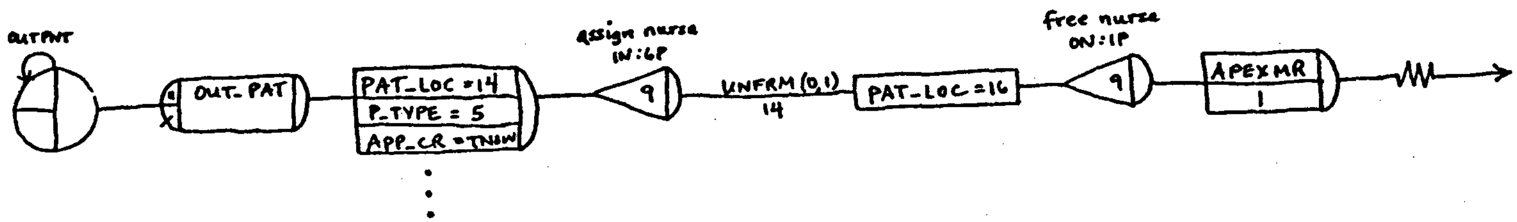
Appendix A: Slam Diagrams

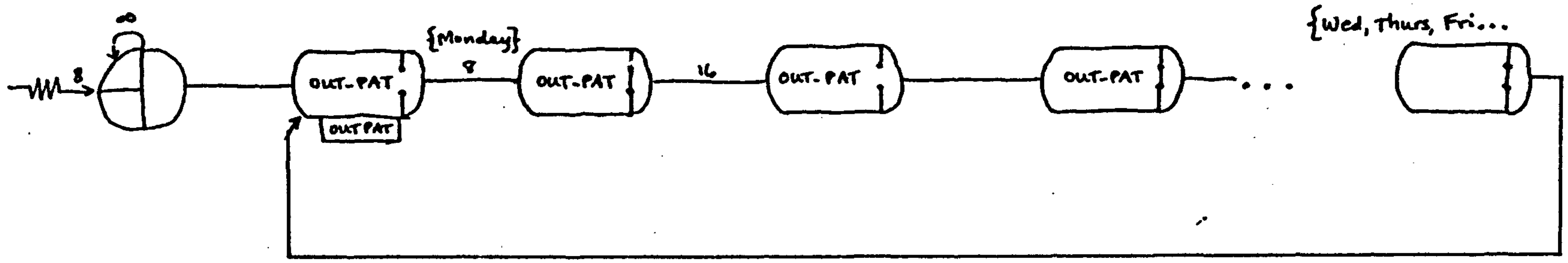


Postpartum Ward

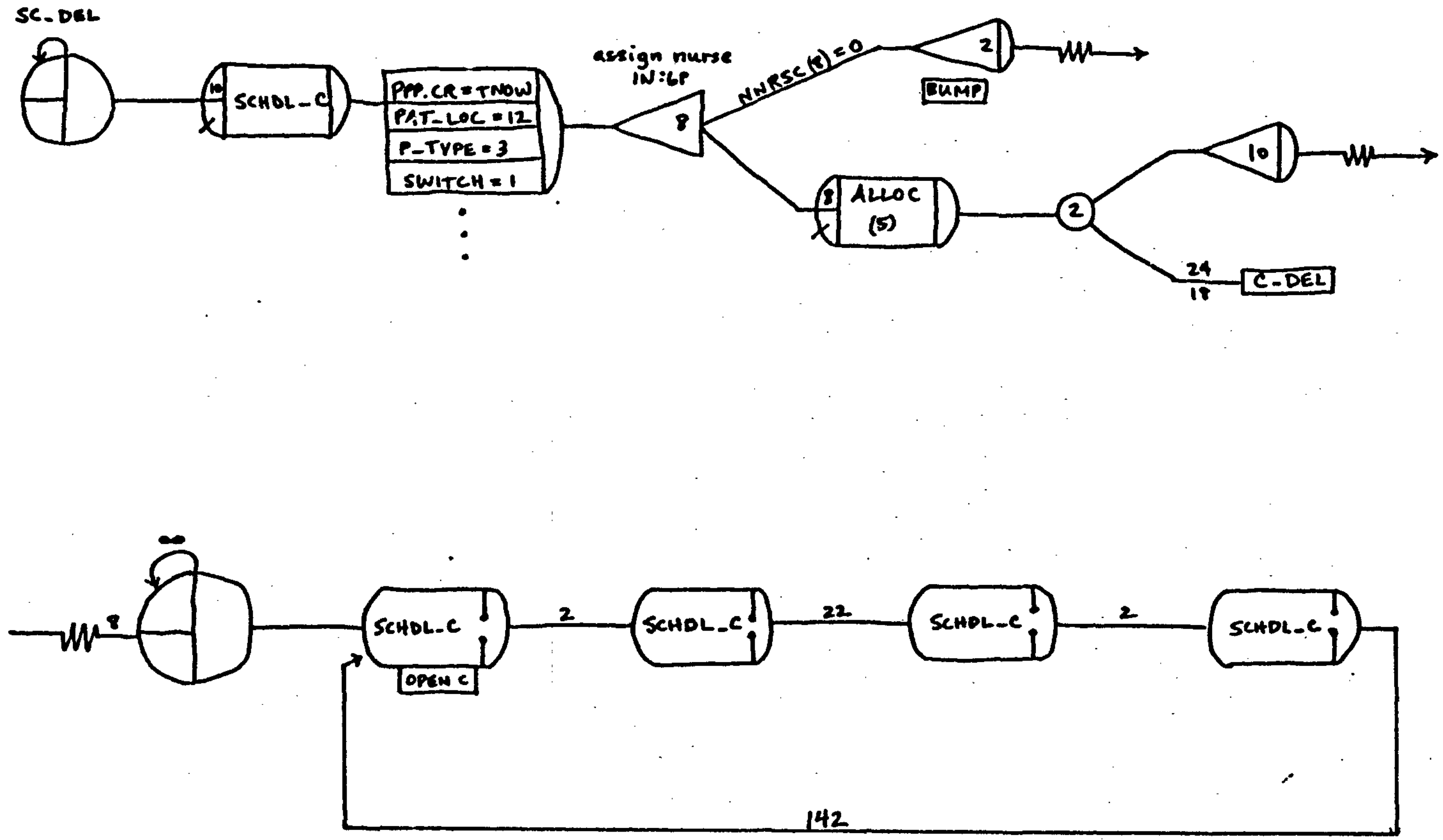


Outpatient Analysis

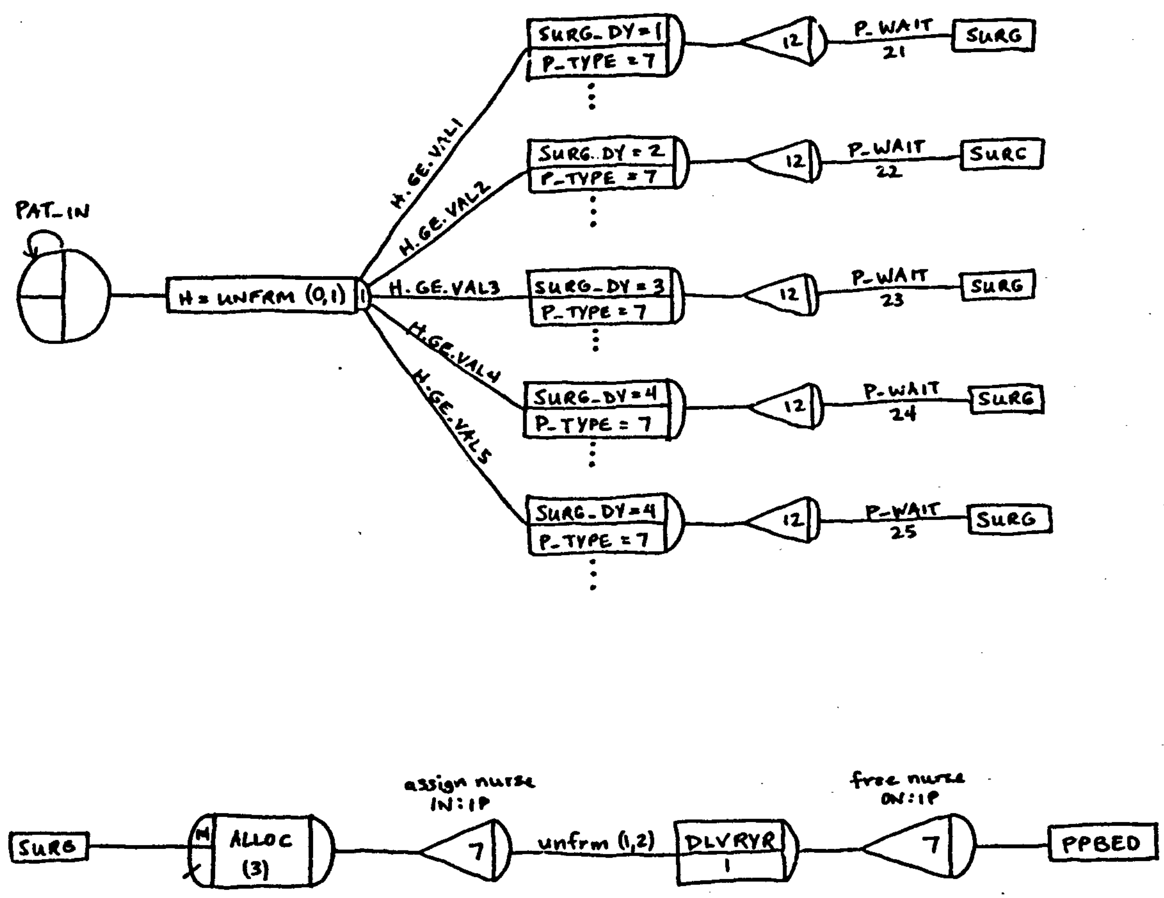




Scheduled C-Sections

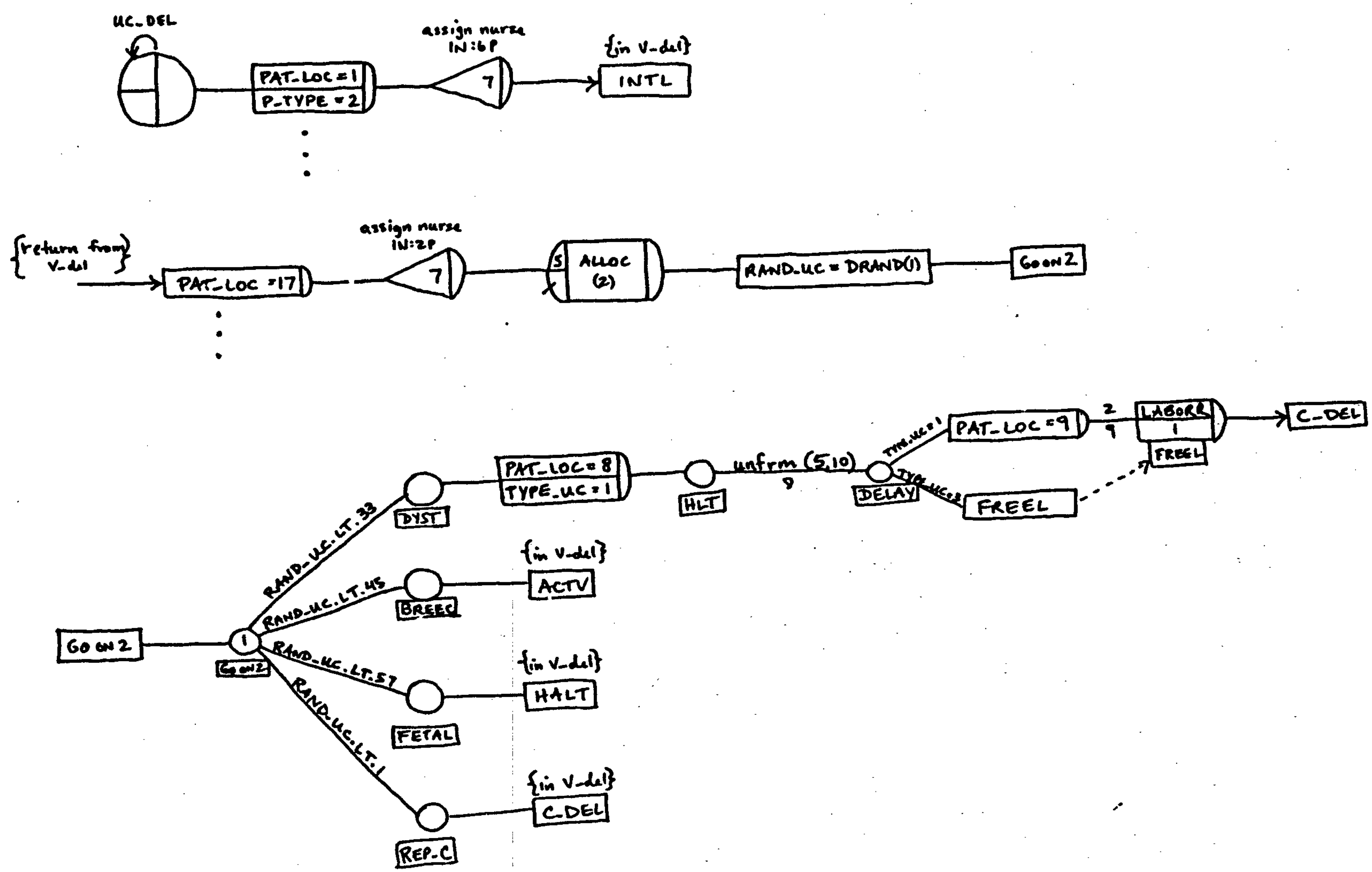


INPATIENT

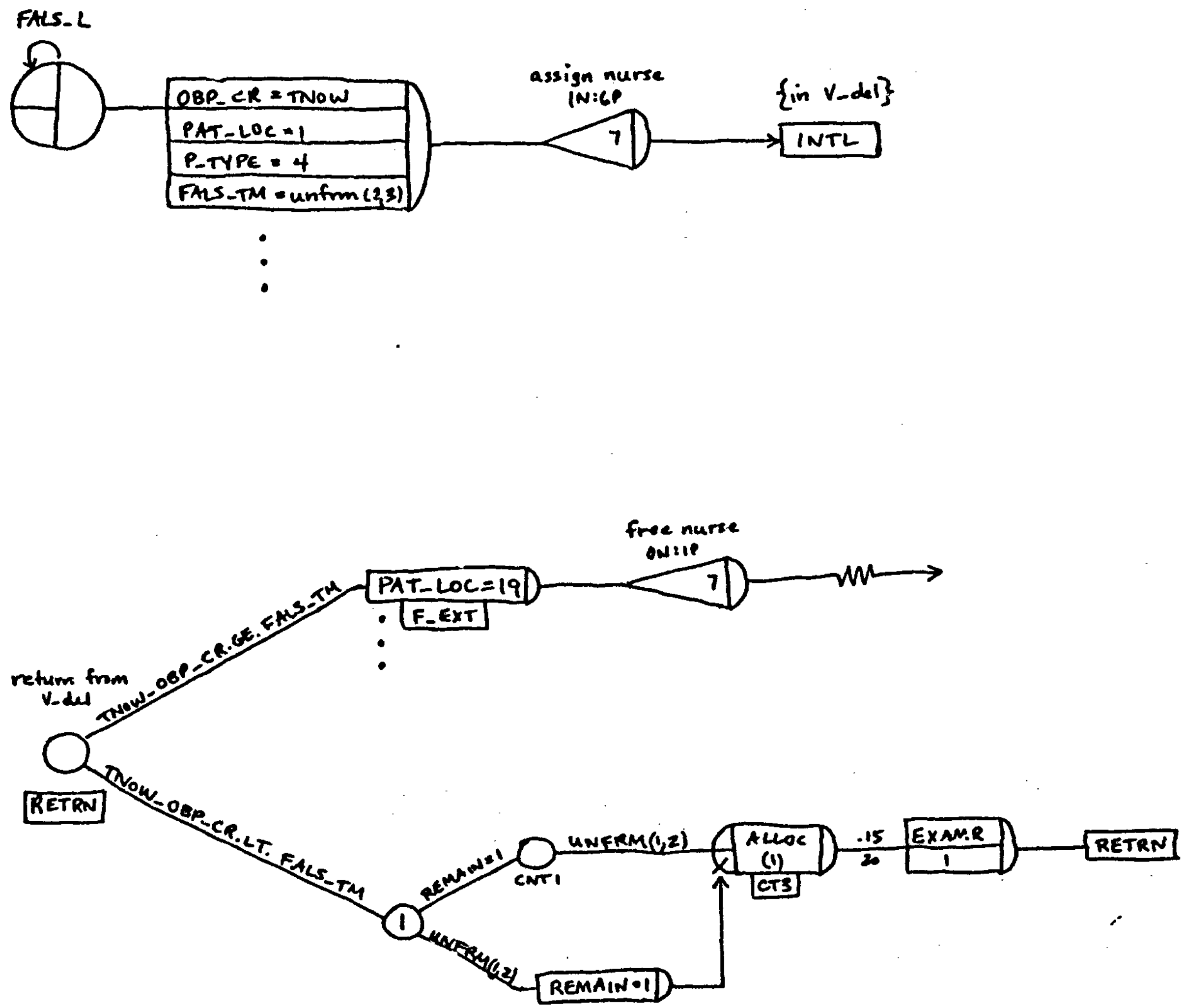


PAT_IN
H = UNFRM (0,1)
H.GE.VAL1
H.GE.VAL2
H.GE.VAL3
H.GE.VAL4
H.GE.VAL5
SURG_DY = 1
P_TYPE = 7
SURG_DY = 2
P_TYPE = 7
SURG_DY = 3
P_TYPE = 7
SURG_DY = 4
P_TYPE = 7
SURG_DY = 4
P_TYPE = 7
12
P_WAIT 21
P_WAIT 22
P_WAIT 23
P_WAIT 24
P_WAIT 25
SURG
SURC
SURG
SURG
SURG
SURG
ALLOC (3)
assign nurse IN:1P
7
unfrm (1,2)
DLVRYR 1
free nurse ON:1P
7
PPBED

UNSCHEDULED C-SECTIONS {REFER BACK TO L + D}

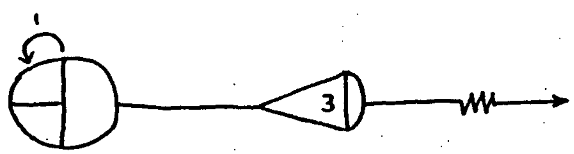


FALSE LABOR

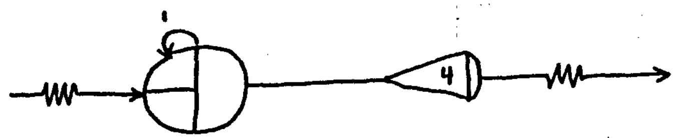


FALS_L
OBP_CR = TNOW
PAT_LOC = 1
P_TYPE = 4
FALS_TM = unfrm(2,3)
assign nurse
IN:6P
7
{in V_del}
INTL
return from
V_del
RETRN
TNOW_OBP_CR.GE. FALS_TM
PAT_LOC=19
F_EXT
free nurse
ON:1P
7
TNOW_OBP_CR.LT. FALS_TM
1
REMAIN=1
CNT1
UNFRM(1,2)
UNFRM(1,2)
REMAIN=1
ALLOC
(1)
CT3
.15
20
EXAM.R
1
RETRN

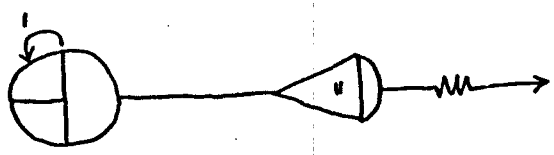
TEST FOR PATIENT DISMISSAL



TRACK HOUR



GENERATE HOURLY NURSE ARRAYS



Appendix B.

Activity, Event Descriptions

Activities

1 vag,unsch cs, and false labor arrival {1N : 6P} -- initial dilation check
2 Early labor {1N : 2P}
3 Active labor {1N : 2P}
4 Stage 2 {1N : 1P}
5 Stage 3 {1N : 1P}
6 Recovery for cesarean patients (monitored outside of ward) {0N :1P}
7 cs delivery {1N : 1P}
8 halt labor for unsch cs delivery {1N : 2P}
9 dystocia additional 2 hour delay {1N :2P}
10 recovery for vaginal deliveries {1N:6P}
11 vag del heading for pp unit {free nurse} {0N:1P}
12 sched cs initial patient arrival to postpartum unit (sign in) {1N :6P}
13 false labor patients remain on ward between dilation check {1N :6P}
14 patients in antepartum testing {1N :1P}
15 patients entering pp ward from ob ward {1N :6P}
16 outpatient appointment over - patient leaving ap unit {0N :P}
17 unsched cs pregnancy progression {1N :2P}
18 sched cs time in pp unit. Wait until c-s deliv {1N :6P}
19 false labor patients depart OB ward {0N :P}
20 false labor patients follow on dilation check {1N :6P}
21 inpatient surgery {1N:1P}
22 pp patient departs pp ward {0N :P}
23 duration of labor for unsched patient

ACTIVITIES: Nurse to Patient Ratios for each of the Wards

```
OB:  {0N:P}  6,11,19
     {1N:1P} 4,5,7
     {1N:2P} 2,3,8,9,17
     {1N:6P} 1,10,13,20

PP:  {0N:P}  22
     {1N:1P}
     {1N:2P}
     {1N:6P} 12,15,18

AP:  {0N:P}  16
     {1N:1P}
     {1N:2P}
     {1N:6P} 14
```

Events

1 Send sched cs patients to cs delivery

2 Bump patient in pp ward

3 Hourly retest of patients in pp ward

4 Check on time of day

5 NONE

6 File arrival of new pp patient

7 Check status of OB nurse

8 Check status of PP nurse

9 Check status of AP nurse

10 File patient arrival to pp ward

11 Generate nurse arrays

12 Schedule inpatient arrivals to coincide with day of surgery. patient enters during duty day

Attribute,File, Resource Declarations

Attributes

```
Atrib(1)  OBP_CR   OB patient creation time
Atrib(2)  PAT_LOC  patient location in network
Atrib(3)  FALS_TM  amount of time false labor patient remains on ward
Atrib(4)  P_TYPE   patient type.  1=vag del 2=unsch cs  3=sched cs
                   4=false labor  5=outpatient  6=inpatient  7=inpatient
Atrib(5)  TYPE_UC  type of unsch cs  1=dystocia  2=fetal  3=breech
                   4=previous cesarean
Atrib(6)  REMAIN   switch to identify a false labor patient looping
                    count patient only once each time through loop
Atrib(7)  BMP_PAT  Switch used to identify patient whose been bumped in sys
Atrib(8)  PPP_CR   PP patient creation time
Atrib(9)  PP_STAY  length of stay in pp ward
Atrib(10) SWITCH   marks sched cs patients reentering pp ward
Atrib(11) APP_CR   AP patient creation time
```

```
Atrib(12) PP_EXIT  Time patient leaves pp ward
Atrib(13) NONE
Atrib(14) NONE
Atrib(15) PAT_ARR   Hour that inpatient arrives to ward
Atrib(16) P_WAIT    Amount of time inpatient waits for day of surgery(outside
                    system)
Atrib(17) UC_DUR    assigns duration of sched s-c patient (uniform distr)
```

Files

```
FILE 1  :  NONE

FILE 2  :  NONE

FILE 3  :  NONE

FILE 4  :  Waiting for Exam Room

FILE 5  :  Waiting for Labor Room

FILE 6  :  Waiting for Delivery Room

FILE 7  :  Waiting for Recovery Room

FILE 8  :  Waiting for Postpartum Room

FILE 9  :  Waiting for Antepartum Room

FILE 10   :  Waiting for sch_c {scheduling cs} for Monday or Tuesday arrival

FILE 11  :   Waiting for outpatient arrivals  {schedule Monday thru Friday}

FILE 12  :   Waiting for inpatient arrivals   {schedule Monday thru Friday}

FILE 13  :  Patients wait in file 13 for duration of postpartum stay

FILE 14  :  Inpatients waiting for delivery room
```

Resources

```
1:  OBNURSE  -  Obstetrical nurse

2:  PPNURSE  -  Postpartum nurse

3:  APNURSE  -  Antepartum nurse

4:  EXAMR    -  Exam room
```

5: LABORR - Labor room

6: DLVRYR - Delivery room

7: RCVRYR - Recovery room

8: PPBEDR - Postpartum room

9: APEXMR - Antepartum room

Real, Integer Declarations

Real Variables

A1	generate prob of sched cs. patient entering system on Monday
A2	generate prob of sched cs.patient entering system on Tuesday
B1	generate prob of inpatient entering system on Monday
B2	generate prob of inpatient entering system on Tuesday
B3	generate prob of inpatient entering system on Wednesday
B4	generate prob of inpatient entering system on Thursday
B5	generate prob of inpatient entering system on Friday
C1	generate prob of outpatient entering system on Monday
C2	generate prob of outpatient entering system on Tuesday
C3	generate prob of outpatient entering system on Wednesday
C4	generate prob of outpatient entering system on Thursday
C5	generate prob of outpatient entering system on Friday
DIFF	difference btwn nurse need and nurses available(incr/decr)
FALSE_1	number of false labor patients in a month
NAP_HR	highest num of L&D nurses needed in an hour
NOB_HR	highest num of L&D nurses needed in an hour
NPP_HR	highest num of L&D nurses needed in an hour
NUM_NRS	# nurses needed every time system is checked
OUT_T1	number of outpatients in a month
PAT_I1	number of inpatients in a month
SC_D1	number of scheduled cesarean deliveries in a month
UC_D1	number of unscheduled cesarean deliveries in a month
VAG_D1	number of vaginal deliveries in a month

Integer Variables

DIFF_DAY	diff in days between when inpatient arrives and day of surgery
AP_EXCS	ap nurse excess
AP_SLAK	ap nurse slack

```
OP_EXCS  l&d nurse excess
OP_SLAK  l&d nurse slack
PP_EXCS  pp nurse excess
PP_SLAK  pp nurse slack
```

Statistical, Global Variable Declaration

Statistical Variables

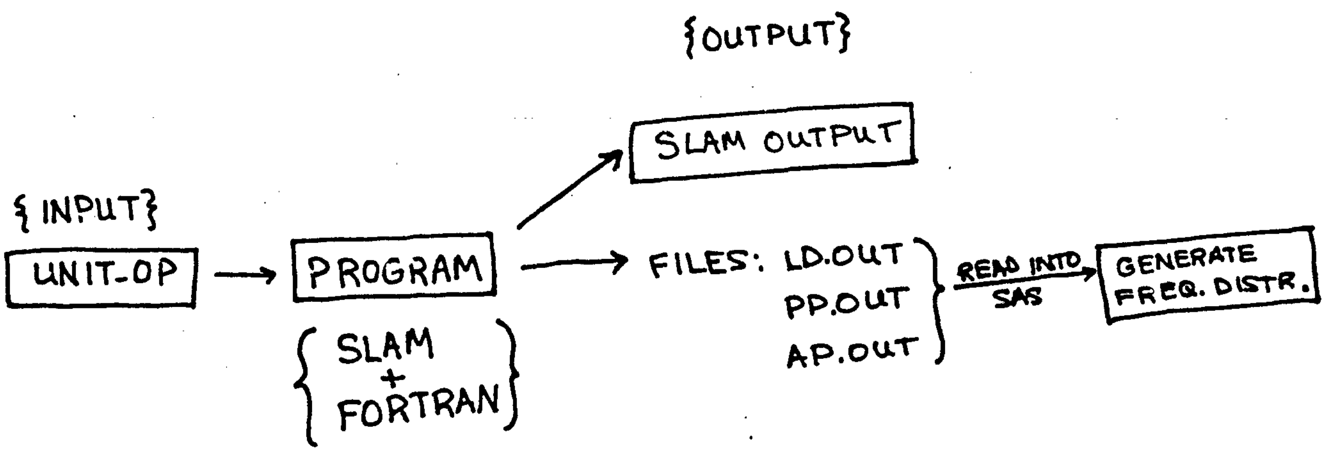
```
STAT 1  Labor & Delivery nurse utilization
STAT 2  Postpartum nurse utilization
STAT 3  Antepartum nurse utilization
STAT 4  Exam room utilization
STAT 5  Labor room utilization
STAT 6  Delivery room utilization
STAT 7  Recovery room utilization
STAT 8  Postpartum room utilization
STAT 9  Antepartum room utilization
STAT 10 Average waiting time for exam room
STAT 11 Average waiting time for labor room
STAT 12 Average waiting time for delivery1 room
STAT 13 Average waiting time for delivery2 room
STAT 14 Average waiting time for recovery room
STAT 15 Average waiting time for postpartum room
STAT 16 Average waiting time for antepartum room
STAT 17 Average waiting time for scheduled c-s patients for system entry
STAT 18 Average waiting time for outpatients for system entry
STAT 19 Average waiting time for inpatients for system entry
STAT 20 NONE
STAT 21 Avg L&D nurse availability
STAT 22 Avg L&D nurse utilization
STAT 23 Stnd dev of L&D utilization
STAT 24 Avg number of entries in pp ward
STAT 25 Avg time of patients in pp ward
STAT 26 Max number of entries in pp ward
STAT 27 Time remaining in ward for bumped patients
STAT 28 Avg bumped time for patients bumped from system
STAT 29 Avg Num of patients bumped in system per 100 week period
STAT 30 Stnd devation of exam room
STAT 31 Stnd devation of labor room
STAT 32 Stnd devation of delivery room
STAT 33 Stnd devation of recovery room
STAT 34 Stnd devation of postpartum room
STAT 35 Stnd devation of antepartum room
```

Global Variables

XX(1)	RAND_UC	Random # genertor for type of unsch cs
XX(2)	VAG_DEL	Mean # of vag delvrs = XX(7)*XX(6) (% vag del)(tot # births/mnth)
XX(3)	SURG_DY	Day of the week when inpatient is sched. for surgery
XX(4)	UC_DEL	Mean # of unsched cs = XX(6)*XX(8)
XX(5)	SC_DEL	Mean # of sched cs = XX(6)*XX(9)
XX(6)	NBIRTH	Total # of births/months
XX(7)	PCT_VAG	% vag delvrs
XX(8)	PCT_UC	% unsched cs
XX(9)	PCT_CS	% sched cs
XX(10)	P_FALSE	# false labor patients/month
XX(11)	OUTPNT	# outpatient tests/month
XX(12)	NLABORR	# labor rooms
XX(13)	NDLVRYR	# delivery rooms
XX(14)	NEXAMR	# exam rooms
XX(15)	NPPBEDR	# postpartum rooms
XX(16)	NRCVRYR	# recovery rooms
XX(17)	NAPEXMR	# antepartum rooms
XX(18)	NONE	
XX(19)	PAT_IN	# inpatient tests/month
XX(20)	HR_CNT	reset to zero every hour - store largest value
XX(21)	DAY_CNT	reset to zero every day - store largest value
XX(22)	ST_OBHR	store value for ob reqd in an hour
XX(23)	ST_OBDY	store largest value for ob reqd in a day
XX(24)	ST_APHR	store largest value for ap reqd in an hour
XX(25)	ST_APDY	store largest value for ap reqd in a day
XX(26)	ST_PPHR	store largest value for ap reqd in an hour
XX(27)	ST_PPDY	store largest value for ap reqd in a day
XX(28)	TRAK_OB	used to increment/decrement ob nurse values
XX(29)	TRAK_PP	used to increment/decrement pp nurse values
XX(30)	TRAK_AP	used to increment/decrement ap nurse values
XX(31)	H	sends inpatient to day of week using probabilities
XX(32)	AVG_PPP	number of pp patients in system. used for steady-state NO
XX(33)	HH	duration of unsched c-s birth
XX(34)	SUM_WT	determines how long inpatient must wait for day of surgery
XX(35)	NUM_UES	tracks number of inpatients waiting for surgery
XX(36)	N	counter for pp patients
XX(37)	AVG_WAT	avg wait for inpatients waiting for surgery
XX(38)	P_BUMP	number of pp patients bumped from system -no beds avail
XX(39)	PS_SCM	prob of sched c-s patient entering on Monday
XX(40)	PS_SCT	prob of sched c-s patient entering on Tuesday
XX(41)	PR_INM	prob of inpatient entering on Monday
XX(42)	PR_INT	prob of inpatient entering on Tuesday
XX(43)	PR_INW	prob of inpatient entering on on Wednesday
XX(44)	PR_INTH	prob of inpatient entering on on Thursday
XX(45)	PR_INF	prob of inpatient entering on on Friday
XX(46)	PR_OUTM	prob of outpatient entering on Monday
XX(47)	PR_OUTT	prob of outpatient entering on Tuesday
XX(48)	PR_OUTW	prob of outpatient entering on on Wednesday

```
XX(49) PR_OUTTH  prob of outpatient entering on on Thursday
XX(50) PR_OUTF   prob of outpatient entering on on Friday
XX(51) W_END_CS  duration of weekend (in hours) based on closing time for c-s
XX(52) W_END_OP  duration of weekend (in hours) based on closing time for outp
XX(53) W_END_IP  duration of weekend (in hours) based on closing time for inp
XX(54) DIF1_SC   time that sched c-s patients can enter ward -- ward open
XX(55) DIF2_SC   time that sched c-s patients can't enter ward -- ward closed
XX(56) DIF1_OP   time that sched outpatients can enter ward -- ward open
XX(57) DIF2_OP   time that sched outpatients can't enter ward -- ward closed
XX(58) DIF1_IP   time that inpatients can enter ward -- ward open
XX(59) DIF2_IP   time that inpatients can enter ward -- ward closed
XX(60) PP_R_M    Start of window or release for PP patients released after this time (hospital po
XX(61) PP_R_E     End of window or release for PP patients released after this time (hospital pol
XX(62) T_SC_M     Start of window to admit sced CS patients to ward (hospital policy)
XX(63) T_SC_E     End of window to admit sced CS patients to ward (hospital policy)
XX(64) T_[illegible]_M     Start of window to admit inpatients to ward (hospital policy)
XX(65) [illegible]N_E      End of window to admit inpatients to ward (hospital policy)
XX(66) [illegible]_OUT_M   Start of window to admit outpatients to ward (hospital policy)
XX(67) T_OUT_E    End of window to admit inpatients to ward (hospital policy)
XX(68) DUR_CES    duration of cesarean stay in pp ward
XX(69) DUR_INP    duration of cesarean stay in pp ward
XX(70) DUR_VAG    duration of cesarean stay in pp ward
```

Program Overview



Appendix C.

SLAM Program Code

```
GEN,STEPHENS,THESIS,11/25/1992,20,,,,,Y/20,72;
LIMITS,20,30,70;

STAT,1,L & D NURSE UTE;
STAT,2,PP NURSE UTE;
STAT,3,AP NURSE UTE;
STAT,4,EXAM ROOM UTE;
STAT,5,LABOR ROOM UTE;
STAT,6,DELVRY ROOM UTE;
STAT,7,RECVRY ROOM UTE;
STAT,8,PP ROOM UTE;
STAT,9,AP ROOM UTE;
STAT,10,AVG WAIT EXAM;
STAT,11,AVG WAIT LABOR;
STAT,12,AVG WAIT DLVRY1;
STAT,13,AVG WAIT DLVRY2;
STAT,14,AVG WAIT RCVRY;
STAT,15,AVG WAIT PPBED;
STAT,16,AVG WAIT APEXM;
STAT,17,AVG SCH.C WAIT;
STAT,18,AVG OUTPT WAIT;
STAT,19,AVG INPAT WAIT;
;STAT,20,N ;
STAT,21,AVAIL LDN;
STAT,22,LDN CHANGED;
STAT,23,STNDDEV;
STAT,24,AVG # IN PP;
STAT,25,AVG WAIT IN PP;
STAT,26,MAX IN PP;
STAT,27,BMP TME;
STAT,28,AVG BMP TME;
STAT,29,AVG NUM BMPD;
STAT,30,S_D EXAM;
STAT,31,S_D LABR;
STAT,32,S_D DLVRY;
STAT,33,S_D RCVRY;
STAT,34,S_D PP ROOM;
STAT,35,S_D AP ROOM;

PRIORITY/8,LVF(12);
PRIORITY/10,LVF(8);
PRIORITY/11,LVF(11);
PRIORITY/13,LVF(12);
```

```
EQUIVALENCE/XX(1),RAND_UC/XX(2),VAG_DEL/XX(4),UC_DEL;
EQUIVALENCE/XX(3),SURG_DY;
EQUIVALENCE/XX(5),SC_DEL/XX(6),NBIRTH/XX(7),PCT_VAG/XX(8),PCT_UC;
EQUIVALENCE/XX(9),PCT_SC/XX(10),P_FALSE/XX(11),OUTPNT;
EQUIVALENCE/XX(12),NLABORR/XX(13),NDLVRYR/XX(14),NEXAMR;
EQUIVALENCE/XX(15),NPPBEDR/XX(16),NRCVRYR/XX(17),NAPEXMR;
EQUIVALENCE/XX(19),PAT_IN/XX(20),HR_CNT;
EQUIVALENCE/XX(21),DAY_CNT/XX(22),ST_OBHR/XX(23),ST_OBDY;
EQUIVALENCE/XX(24),ST_APHR/XX(25),ST_APDY/XX(26),ST_PPHR;
EQUIVALENCE/XX(27),ST_PPDY/XX(28),TRAK_OB/XX(29),TRAK_PP;
EQUIVALENCE/XX(30),TRAK_AP/XX(31),H/XX(33),HH;
EQUIVALENCE/XX(34),SUM_WT/XX(35),NUM_OBS;
EQUIVALENCE/XX(32),AVG_PPP;
EQUIVALENCE/XX(36),N;
EQUIVALENCE/XX(37),AVG_WAT;
EQUIVALENCE/XX(38),P_BUMP;
EQUIVALENCE/XX(39),PR_SCM/XX(40),PR_SCT/XX(41),PR_INM;
EQUIVALENCE/XX(42),PR_INT/XX(43),PR_INW/XX(44),PR_INTH;
EQUIVALENCE/XX(45),PR_INF/XX(46),PR_OUTM/XX(47),PR_OUTT;
EQUIVALENCE/XX(48),PR_OUTW/XX(49),PR_OTTH/XX(50),PR_OUTF;
EQUIVALENCE/XX(51),W_END_CS/XX(52),W_END_OP/XX(53),W_END_IP;
EQUIVALENCE/XX(54),DIF1_SC/XX(55),DIF2_SC/XX(56),DIF1_OP;
EQUIVALENCE/XX(57),DIF2_OP/(XX(58),DIF1_IP/XX(59),DIF2_IP;
EQUIVALENCE/XX(60),PP_R_M/XX(61),PP_R_E/XX(62),T_SC_M;
EQUIVALENCE/XX(63),T_SC_E/XX(64),T_IN_M/XX(65),T_IN_E;
EQUIVALENCE/XX(66),T_OUT_M/XX(67),T_OUT_E;
EQUIVALENCE/XX(68),DUR_CES/XX(69),DUR_INP/XX(70),DUR_VAG;


;ATTRIBUTES
EQUIVALENCE/ATRIB(1),OBP_CR/ATRIB(2),PAT_LOC/ATRIB(3),FALS_TM;
EQUIVALENCE/ATRIB(4),P_TYPE/ATRIB(5),TYPE_UC/ATRIB(6),REMAIN;
EQUIVALENCE/ATRIB(8),PPP_CR/ATRIB(9),PP_STAY/ATRIB(10),SWITCH;
EQUIVALENCE/ATRIB(7),BMP_PAT/ATRIB(12),PP_EXIT;
EQUIVALENCE/ATRIB(11),APP_CR;
EQUIVALENCE/ATRIB(15),PAT_ARR/ATRIB(16),P_WAIT;
EQUIVALENCE/ATRIB(17),UC_DUR;


SEEDS,4367651(1),6121127(2),8956419(3),5732737(4);
SEEDS,4161987(5),4367651(6);

;******GENERATE PLOT TO DETERMINE STEADY-STATE
;RECORD,TNOW,TIME,0,P,1.;
;VAR,XX(36),#, PPP # IN SYS;

NETWORK;
```

```
GATE/1,SCHDL_C,CLOSE,10/2,OUT_PAT,CLOSE,11;


RESOURCE/1,OBNURSE(0),1/2,PPNURSE(0),2/3,APNURSE(0),3;
RESOURCE/4,EXAMR(NEXAMR),4/5,LABORR(NLABORR),5;
RESOURCE/6,DLVRYR(NDLVRYR),6,14/7,RCVRYR(NRCVRYR),7;
RESOURCE/8,PPBEDR(NPPBEDR),8/9,APEXMR(NAPEXMR),9;


;**********VAG DELIVERIES***********

VAG    CREATE,EXPON(VAG_DEL,1);                   creation vag deliveries
       ASSIGN,P_TYPE=1,PAT_LOC=1,OBP_CR=TNOW;     l&d patient just arrived
       EVENT,7;                                   assign l&d nurse
INTL   AWAIT(4),ALLOC(1);                         assign exam room
       ACT/1,.15;                                 check dilation;
       FREE,EXAMR;                                free exam room
       GOON,1;
       ACT,,P_TYPE.EQ.4,RETRN;                    false labor patient
       ACT,,P_TYPE.EQ.2,PRGRS;                    birth type = unsch cs birth
       ACT;                                       continue with vag deliv
       AWAIT(5),ALLOC(2);                         assign labor room
ACTV   EVENT,7;                                   assign l&d nurse
       ASSIGN,PAT_LOC=3;                          vag patient in active labor
       GOON,1;
       ACT,,TYPE_UC.EQ.2,FREEL;                   birth type = unsch cs birth
       ACT;
       GOON;
       ACT/3,EXPON(3.47);                         active labor duration
       FREE,LABORR;                               free labor room
STG_2  ASSIGN,PAT_LOC=4;                          l&d patient in 2nd stg of labor
       EVENT,7;                                   assign l&d nurse
       AWAIT(6),ALLOC(3);                         assign delivery room
       ACT/4,GAMA(1,.62);                         stage 2 duration
STG3   ASSIGN,PAT_LOC=5;                          l&d patient 3rd stg of labor
       ACT/5,GAMA(1,.25);                         stage 3 duration
       FREE,DLVRYR;                               free delivery room

RCVRY  GOON,1;
       ACT,,P_TYPE .EQ. 1,VREC;
       ACT;
       ASSIGN,PAT_LOC=6;                          cesarean patients in recovery;
       EVENT,7;                                   free l&d nurse
       ACT/6,1;                                   cesareans monitored for 1 hr
       AWAIT(7),ALLOC(4);                         assign recovery room
       ACT/10,1;                                  recovery duration
       FREE,RCVRYR;                               free recovery room
       GOON;
```

```
      ACT,,,PPBED;                                 cesarean headed to pp ward
      TERM;
VREC  ASSIGN,PAT_LOC=10;                           l&d patient in recovey
      EVENT,7;                                     check l&d nurse
      AWAIT(5),ALLOC(2);                           assign labor room
      ACT/10,GAMA(1,3.05);                         recovery duration
      FREE,LABORR;                                 free labor room
      ASSIGN,PAT_LOC=11;                           vag del go to ppbed.free nurse
      EVENT,7;                                     free l&d nurse
      ACT,,,PPBED;                                 done with l&d -- go to ppbed
      TERM;


;**********UNSCHEDULED C-SECTION DELIVERY*******


UNS_C CREATE,EXPON(UC_DEL,2);                      create unsched cs births
      ASSIGN,P_TYPE=2,PAT_LOC=1,OBP_CR=TNOW;       l&d unsch cs patient arrival
      EVENT,7;                                     assign l&d nurse
      ACT,,,INTL;
PRGRS ASSIGN,PAT_LOC=17;                           unsch cs progression {chng ratio}
      EVENT,7;                                     assign l&d nurse {free nurse}
      AWAIT(5),ALLOC(2);                           assign labor room
      ASSIGN,RAND_UC=DRAND(1);                     generate rv for type of unsch cs
      GOON,1;
;                                                  adjust values to equal 1
      ACT,,RAND_UC .LE. .33,DYST;                  % unsch cs birth = dystocia
      ACT,,RAND_UC .LE. .45,FETAL;                 & unsch cs birth = fetal
      ACT,,RAND_UC .LE. .57,BREEC;                 % unsch cs birth = breech
      ACT,,RAND_UC .LE. 1.0,REP_C;                 % unsch cs birth = repeat cs

DYST  ASSIGN,TYPE_UC=1,PAT_LOC=8;                  unsch cs birth = dystocia
HLT   GOON;
      ACT/8,UNFRM(5,10);                           halt labor
DELAY GOON,1;
      ACT,,TYPE_UC .EQ. 1,GN3;                     unsch cs birth = dystocia
      ACT,,TYPE_UC .EQ. 3,FREEL;                   unsch cs birth = breech
GN3   ASSIGN,PAT_LOC=9;                            patient at dystocia 2 hr delay
      ACT/9,2;                                     dystocia 2 hour delay
FREEL FREE,LABORR;                                 free labor room
C_DEL GOON;
      ASSIGN,PAT_LOC=7;                            patient at cs operation
      EVENT,7;                                     check nurse status
      AWAIT(6),ALLOC(3);                           assign delivery room
      ACT/7,UNFRM(1,2);                            cs operation duration
      FREE,DLVRYR;                                 free delivery room
      ACT,,,RCVRY;                                 patient goes to recovery
      TERM;
FETAL ASSIGN,TYPE_UC=3;                            unsch cs birth = fetal
      ACT,,,HLT;
```

```
 BREEC ASSIGN,TYPE_UC=2;                           unsch cs birth = breech
       ACT,,,ACTV;
 REP_C ASSIGN,TYPE_UC=4;                           unsch cs birth = repeat cs
       ASSIGN,HH=EXPON(3.47);
       ASSIGN,UC_DUR=UNFRM(0,HH);
       ACT,UC_DUR;                                 unsch cs duration
       GOON;
       ACT,,,FREEL;


 ;*********SCHEDULED C-SECTION DELIVERIES************


 SCH_C CREATE,EXPON(SC_DEL,3);                     create scheduled cs births
       AWAIT(10),SCHDL_C;                          schedule cs entries Mon/Tues
       ASSIGN,P_TYPE=3,PAT_LOC=12,PPP_CR=TNOW;     birth type = scheduled cs
       ASSIGN,SWITCH=1;
       ASSIGN,PP_STAY=DUR_CES;
       ASSIGN,PP_EXIT=TNOW+PP_STAY;
       assign,n=n+1;

       EVENT,8;                                    assign pp nurse
       GOON,1;
       ACT,,NNRSC(8) .EQ. 0.,BUMP;                 no ppbeds - bump mom
       ACT;
       AWAIT(8),ALLOC(5);                          assign pp bed
       GOON,2;
       ACT,,,A1;
       ACT,,,A2;
 A1    EVENT,10;                                   file patient for pp stay
       TERM;
 A2    GOON;
       ACT/18,24;                                  schd c-s patnt entry- pp unit
       ACT,,,C_DEL;
       TERM;

 C1    CREATE,,T_SC_M;                             this part generates caesarian
       ACT;                                        arrivals on Monday or Tuesday.
 OPENC OPEN,SCHDL_C;                               Patients arrive between specific
       ACT,DIF1_SC;                                hours;  no entries on Sat/Sun
       CLOSE,SCHDL_C;
       ACT,DIF2_SC;
       OPEN,SCHDL_C;
       ACT,DIF1_SC;
       CLOSE,SCHDL_C;
       ACT,W_END_CS,,OPENC;
 FIN   TERM;


 ;**********FALSE LABOR ARRIVALS****************
```

```
FLS_L CREATE,EXPON(P_FALSE,4);                    create false labor arrivals
      ASSIGN,PAT_LOC=1,P_TYPE=4,OBP_CR=TNOW;      patient arriving to l&d unit
      ASSIGN,FALS_TM=UNFRM(2,3);                  store false labor patient stay
      EVENT,7;                                    assign l&d nurse
      ACT,,,INTL;                                 first pass through exam
RETRN GOON,1;
      ACT,,TNOW-OBP_CR .GE. FALS_TM,F_EXT;        send patient home
      ACT;                                        false labor patient remains
      GOON,1;
      ACT,,REMAIN.EQ.1,CNT1;                      marker to identify patient
      ACT;
      GOON;
      ACT/13,UNFRM(1,2);                          patient remains in l&d unit
      ASSIGN,REMAIN=1;                            identifies patient in ward
      ACT,,,CT3;
CNT1  GOON;
      ACT,UNFRM(1,2);                             patient looping in retrn
CT3   AWAIT(4),ALLOC(1);                          assign exam room
      ACT/20,.15;                                 duration of dilation check
      FREE,EXAMR;                                 free exam room
      ACT,,,RETRN;
F_EXT ASSIGN,PAT_LOC=19;                          patient leaving
      EVENT,7;                                    free l&d nurse
END1  TERM;


;**********POSTPARTUM WARD*************

PPBED  GOON,1;
      ACT,,SWITCH.EQ.1,ED3;                       sched cs patient already has bed
      ACT;
      assign,n=n+1;
      goon,1;
      act,,p_type .eq. 1,rte1;                    patient=vaginal birth
      act,,p_type .eq. 7,rt2;                     patient=inpatient
      act;
      ASSIGN,PPP_CR=TNOW,PP_STAY=DUR_CES;         UNSCH C-S at pp ward
      ACT,,,CON;
RT2   ASSIGN,PPP_CR=TNOW,PP_STAY=DUR_INP;         INPATIENT at pp ward
      ACT,,,CON;
RTE1  ASSIGN,PPP_CR=TNOW,PP_STAY=DUR_VAG;         VAG DEL arrival at pp ward
CON   ASSIGN,PP_EXIT=TNOW+PP_STAY;
      ASSIGN,PAT_LOC=15,P_TYPE=6;                 patient in pp ward
      GOON,1;
      ACT,,NNRSC(8).EQ.0.,BUMP;                   no ppbeds - bump mom
      ACT,,,CHK5;                                 available pp bed space
BUMP  EVENT,2;                                    bump longest remaining patient
```

```
       TERM;
CHK5   EVENT,8;                                    assign pp nurse
       AWAIT(8),ALLOC(5);                          assign pp bed
       EVENT,10;                                   file patient for pp stay
       GOON;
       ENTER,3;                                    bumped patient reenters to exit
ED3    TERM;



;**********OUTPATIENT ARRIVALS**************


       CREATE.EXPON(OUTPNT,5);                     create antepartum arrivals
       AWAIT(11),OUT_PAT;                          wait for Mon-Fri appointment
       ASSIGN,PAT_LOC=14,APP_CR=TNOW,P_TYPE=5;     ap patient location
       EVENT,9;                                    assign ap nurse
       AWAIT(9),ALLOC(6);                          assign ap room
       ACT/14,UNFRM(0,1);                          outpatient testing duration
       ASSIGN,PAT_LOC=16;                          patient leaving ap unit
       EVENT,9;                                    check ap nurse status
       FREE,APEXMR;                                free ap room
       TERM;



;                                                  this part generates outpatient
;                                                  arrivals Mon-Fri. Time variable.

       CREATE,,T_OUT_M;
OUTPT  OPEN,OUT_PAT;                               Monday open
       ACT,DIF1_OP;
       CLOSE,OUT_PAT;                              Monday close
       ACT,DIF2_OP;
       OPEN,OUT_PAT;                               Tuesday open
       ACT,DIF1_OP;
       CLOSE,OUT_PAT;                              Tuesday close
       ACT,DIF2_OP;
       OPEN,OUT_PAT;                               Wednesday open
       ACT,DIF1_OP;
       CLOSE,OUT_PAT;                              Wednesday close
       ACT,DIF2_OP;
       OPEN,OUT_PAT;                               Thursday open
       ACT,DIF1_OP;
       CLOSE,OUT_PAT;                              Thursday close
       ACT,DIF2_OP;
       OPEN,OUT_PAT;                               Friday open
       ACT,DIF1_OP;
```

```
        CLOSE,C    PAT;                               Friday close
        ACT,W_.    .P,,OUTPT;                         Sat & Sun (48 hrs),Monday(TBD)
        TERM;                                         Friday (TBD)


;**********INPATIENT ARRIVALS**************

        CREATE,EXPON(PAT_IN,6),,1;                    create antepartum arrivals
        ASSIGN,H=UNFRM(0,1);
        ASSIGN,PAT_ARR=HR_CNT;                        store hour of patient arrival
        GOON,1;
        ACT,,H .GE. PR_INM,S_1;                       prob of entering Monday
        ACT,,H .GE. PR_INT, S_2 ;                     prob of entering Tuesday
        ACT,,H .GE. PR_INW,S_3;                       prob of entering Wednesday
        ACT,,H .GE.PR_INTH,S_4;                       prob of entering Thursday
        ACT,,H .GE.PR_INF,S_5;                        prob of entering Friday
S_1     ASSIGN,SURG_DY=1;                             surgery day = Monday
        ASSIGN,PAT_LOC=10,OBP_CR=TNOW,P_TYPE=7;
        EVENT,12;                                     determine patient wait
        ACT/21,P_WAIT,,SURG;                          patient waits till surg day
        TERM;
S_2     ASSIGN,SURG_DY=2;                             surgery day = Tuesday
        EVENT,12;                                     determine patient wait
        ASSIGN,PAT_LOC=10,OBP_CR=TNOW,P_TYPE=7;
        ACT/22,P_WAIT,,SURG;                          patient waits till surg day
        TERM;
S_3     ASSIGN,SURG_DY=3;                             surgery day = Wednesday
        EVENT,12;                                     determine patient wait
        ASSIGN,PAT_LOC=10,OBP_CR=TNOW,P_TYPE=7;
        ACT/23,P_WAIT,,SURG;                          patient waits till surg day
        TERM;
S_4     ASSIGN,SURG_DY=4;                             surgery day = Thursday
        EVENT,12;                                     determine patient wait
        ASSIGN,PAT_LOC=10,OBP_CR=TNOW,P_TYPE=7;
        ACT/24,P_WAIT,,SURG;                          patient waits till surg day
        TERM;
S_5     ASSIGN,SURG_DY=5;                             surgery day = Friday
        EVENT,12;                                     determine patient wait
        ASSIGN,PAT_LOC=10,OBP_CR=TNOW,P_TYPE=7;
        ACT/25,P_WAIT,,SURG;                          patient waits till surg day
        TERM;

SURG    GOON;
;        ASSIGN,SUM_WT=SUM_WT-P_WAIT;
;        ASSIGN,NUM_OBS=NUM_OBS-1;
        AWAIT(14),ALLOC(3);                           assign delvry room
        ACT,UNFRM(1,2);                               inpatient surgery duration
        FREE,DLVRYR;                                  free delivery room
```

```
     GOON;
     ACT,,,PPBED;
     TERM;



;**********TEST PP PATIENTS FOR DISMISSAL ********

     CREATE,1;                                        retest patient
     EVENT,3;
     TERM;


;**********TRACK HOUR/DAY    ******************

     CREATE,1,1;
     EVENT,4;                                         determine time of day
     TERM;


;**********GENERATE HOURLY NURSE ARRAYS *********

     CREATE,1;                                        update every hour
     EVENT,11;
     TERM;


     END;

INIT,0,17800,Y/1;
MONTR,CLEAR,1000;
SIMULATE;
FIN;
```

Appendix D.

FORTRAN Program Code

```
C     PROGRAM FOR DISCRETE/NETWORK COMBINATION
c     PROGRAM READS IN DATA FROM UNIT_OP FILE


      PROGRAM MAIN

CCC   include this line for running on SCGRAPH
c     INCLUDE '/usr/local/Slam/PARAM.INC'
      INCLUDE '/home/scgraph6f/stu/gor/astephen/thesis/PARAM.INC'

      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

C      COMMON VARIABLES ARE DIMENSIONED AS FOLLOWS:
C      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
C      1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
C      2SSL(MEQT), TNEXT, TNOW, XX(MMXXV)


      DIMENSION NSET(20000)
      COMMON QSET(20000)
      EQUIVALENCE (NSET(1),QSET(1))
      NNSET=20000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      OPEN(UNIT=NCRDR,FILE='fort.5',STATUS='UNKNOWN')
      OPEN(UNIT=NPRNT,FILE='fort.6',STATUS='UNKNOWN')
      OPEN(UNIT=25,FILE='UNIT_OP',STATUS='UNKNOWN')
      OPEN(UNIT=26,FILE='ld.out',STATUS='UNKNOWN')
      OPEN(UNIT=27,FILE='ap.out',STATUS='UNKNOWN')
      OPEN(UNIT=28,FILE='pp.out',STATUS='UNKNOWN')
      CALL SLAM
      CLOSE(5)
      CLOSE(6)
      CLOSE(25)
      CLOSE(26)
      CLOSE(27)
      CLOSE(28)
      STOP
      END
```

```
      SUBROUTINE INTLC

      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

      COMMON/UCOM1/NOB_HR(24),NOB_DAY(7),NAP_HR(24),NAP_DAY(7),
     *NPP_HR(24),NPP_DAY(7)

      REAL NOB_HR(24),NOB_DAY(7),NAP_HR(24),NAP_DAY(7),NPP_HR(24),
     *NPP_DAY(7)

      REAL VAG_D1,UC_D1,SC_D1,PAT_I1,OUT_T1,FALSE_1,A1,A2,B1,B2,B3,
     *B4,B5,C1,C2,C3,C4,C5

      INTEGER DIFF_DAY

      EQUIVALENCE (XX(2),VAG_DEL),(XX(4),UC_DEL),
      EQUIVALENCE (XX(5),SC_DEL),(XX(3),SURG_DY)
      EQUIVALENCE (XX(6),NBIRTH),(XX(7),PCT_VAG),(XX(8),PCT_UC)
      EQUIVALENCE (XX(9),PCT_SC),(XX(10),P_FALSE),(XX(11),OUTPNT)
      EQUIVALENCE (XX(12),NLABORR),(XX(13),NDLVRYR),(XX(14),NEXAMR)
      EQUIVALENCE (XX(15),NPPBEDR),(XX(16),NRCVRYR),(XX(17),NAPEXMR)
      EQUIVALENCE (XX(19),PAT_IN),(XX(20),HR_CNT)
      EQUIVALENCE (XX(21),DAY_CNT),(XX(32),AVG_PPP),(XX(34),SUM_WT)

      EQUIVALENCE (XX(38),P_BUMP),(XX(36),N)
      EQUIVALENCE (XX(39),PR_SCM),(XX(40),PR_SCT),(XX(41),PR_INM)
      EQUIVALENCE (XX(42),PR_INT),(XX(43),PR_INW),(XX(44),PR_INTH)
      EQUIVALENCE (XX(45),PR_INF),(XX(46),PR_OUTM),(XX(47),PR_OUTT)
      EQUIVALENCE (XX(48),PR_OUTW),(XX(49),PR_OTTH),(XX(50),PR_OUTF)
      EQUIVALENCE (XX(51),W_END_CS),(XX(52),W_END_OP),(XX(53),W_END_IP)
      EQUIVALENCE (XX(54),DIF1_SC),(XX(55),DIF2_SC),(XX(56),DIF1_OP)
      EQUIVALENCE (XX(57),DIF2_OP),(XX(58),DIF1_IP),(XX(59),DIF2_IP)
      EQUIVALENCE (XX(60),PP_R_M),(XX(61),PP_R_E),(XX(62),T_SC_M)
      EQUIVALENCE (XX(63),T_SC_E),(XX(64),T_IN_M),(XX(65),T_IN_E)
      EQUIVALENCE (XX(66),T_OUT_M),(XX(67),T_OUT_E)
      EQUIVALENCE (XX(68),DUR_CES),(XX(69),DUR_INP),(XX(70),DUR_VAG)

C     INITIALIZE VALUES OF COUNTERS, PARAMETERS

      DAY_CNT = 1.
      HR_CNT = 0.
      SUM_WT=0
      NUM_OBS=0
      AVG_PPP = 0.
      N=0
      P_BUMP=0
```

```
C     READ IN INFORMATION ON UNIT OPERATION FROM FILE UNIT_OP

      READ(25,*)VAG_D1
      READ(25,*)UC_D1
      READ(25,*)SC_D1
      READ(25,*)PAT_I1
      READ(25,*)OUT_T1
      READ(25,*)FALSE_1
      READ(25,*)NBIRTH
      READ(25,*)PCT_VAG
      READ(25,*)PCT_UC
      READ(25,*)PCT_CS
      READ(25,*)NLABORR
      READ(25,*)NDLVRYR
      READ(25,*)NEXAMR
      READ(25,*)NPPBEDR
      READ(25,*)NRCVRYR
      READ(25,*)NAPEXMR

      READ(25,*)P_SC_M
      READ(25,*)P_SC_T
      READ(25,*)P_IN_M
      READ(25,*)P_IN_T
      READ(25,*)P_IN_W
      READ(25,*)P_IN_TH
      READ(25,*)P_IN_F
      READ(25,*)P_OUT_M
      READ(25,*)P_OUT_T
      READ(25,*)P_OUT_W
      READ(25,*)P_OUTTH
      READ(25,*)P_OUT_F

      READ(25,*)PP_R_M
      READ(25,*)PP_R_E
      READ(25,*)T_SC_M
      READ(25,*)T_SC_E
      READ(25,*)T_IN_M
      READ(25,*)T_IN_E
      READ(25,*)T_OUT_M
      READ(25,*)T_OUT_E

      READ(25,*)DUR_CES
      READ(25,*)DUR_INP
      READ(25,*)DUR_VAG


c     GENERATE INTERARRIVAL TIMES FOR CREATE NODES

      VAG_DEL= 1/(VAG_D1*(1./30.)*(1./24.))
      UC_DEL= 1/(UC_D1*(1./30.)*(1./24.))
```

```
      SC_DEL= 1/(SC_D1*(1./30.)*(1./24.))
      PAT_IN= 1/(PAT_I1*(1./30.)*(1./24.))
      P_FALSE= 1/(FALSE_1*(1./30.)*(1./24.))
      OUTPNT= 1/(OUT_T1*(1./30.)*(1./24.))

C     GENERATE PROBABILITIES FOR PATIENT ENTRY FOR DAYS OF THE WEEK

CC    SCHEDULED CESAREAN PROBABILITIES

      A1=1-P_SC_M
      PR_SCM=A1
      A2=A1-P_SC_T
      PR_SCT=A2

CC    INPATIENT PROBABILITIES

      B1=1-P_IN_M
      PR_INM=B1
      B2=1-P_IN_T
      PR_INT=B2
      B3=1-P_IN_W
      PR_INW=B3
      B4=1-P_IN_TH
      PR_INTH=B4
      B5=1-P_IN_F
      PR_INF=B5

CC    OUTPATIENT PROBABILITIES

      C1=1-P_OUT_M
      PR_OUTM=C1
      C2=1-P_OUT_T
      PR_OUTT=C2
      C3=1-P_OUT_W
      PR_OUTW=C3
      C4=1-P_OUT_TH
      PR_OTTH=C4
      C5=1-P_OUT_F
      PR_OUTF=C5

C     DETERMINE HOURS THAT GATES ARE OPEN FOR SCED C-S PATIENTS

      DIF1_SC=T_SC_E-T_SC_M
      DIF2_SC=24-DIF1_SC
      W_END_CS=5*24+(24-DIF2_SC)

C     DETERMINE HOURS THAT GATES ARE OPEN FOR OUTPATIENTS

      DIF1_OP=T_OUT_E-T_OUT_M
      DIF2_OP=24-DIF1_OP
```

```
      W_END_OP=2*24+(24-DIF2_OP)

      RETURN
      END

      SUBROUTINE EVENT(I)

      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

      COMMON/UCOM1/NOB_HR(24),NOB_DAY(7),NAP_HR(24),NAP_DAY(7),
     *NPP_HR(24),NPP_DAY(7),NOB_OBS(24),Store(72)

      REAL NOB_HR(24),NAP_HR(24),NPP_HR(24),
     *NOB_OBS(24),STORE_A(72),STORE_B(72),STORE_C(72)

      REAL DIFF_DAY

      EQUIVALENCE (XX(20),HR_CNT)
      EQUIVALENCE (XX(21),DAY_CNT),(XX(22),ST_OBHR),
      EQUIVALENCE (XX(24),ST_APHR),(XX(26),ST_PPHR)
      EQUIVALENCE (XX(31),H),(XX(33),HH)
      EQUIVALENCE (XX(34),SUM_WT),(XX(35),NUM_OBS)
      EQUIVALENCE (XX(37),AVG_WAT),(XX(38),P_BUMP)
      EQUIVALENCE (XX(36),N)

C     ATTRIBUTES

      EQUIVALENCE (ATRIB(6),REMAIN),(ATRIB(7),BMP_PAT)
      EQUIVALENCE (ATRIB(8),PPP_CR)
      EQUIVALENCE (ATRIB(10),SWITCH),(ATRIB(11),APP_CR)
      EQUIVALENCE (ATRIB(12),PP_EXIT),(ATRIB(13),PPCRT)
      EQUIVALENCE (ATRIB(15),PAT_ARR)

      DIMENSION BUFFR(17)

      INTEGER J,OB_EXCS,OB_SLAK,PP_EXCS,PP_SLAK,AP_EXCS,AP_SLAK

      REAL DIFF,NUM_NRS

      GO TO (1,2,3,4,5,6,7,8,9,10,11,12), I

      WRITE(6,*) ' ERROR NUMBERING OF EVENTS'
```

```
C ****** SEND SCHEDULED CS PATIENTS TO CS OPERATION *********


1       IF (NNQ(10) .GT. 0) THEN
         CALL RMOVE(1,10,BUFFR)
         CALL ENTER(1,BUFFR)
       ENDIF
       RETURN



C ******** BUMP PATIENT FROM PP WARD **********


C      COLLECT TIME THAT PATIENTS SHOULD HAVE REMAINED IN WARD IF
C      BEDSPACE WAS AVAILABLE

 2     P_BUMP=P_BUMP+1

       J = 1
       BUMP_TM=TNOW-ATRIB(12)
       CALL COLCT(BUMP_TM,27)
23     CALL RMOVE(J,13,BUFFR)

C      IF PATIENT = SCHED CESARIAN PATIENT, DO NOT BUMP.  CHOOSE NEXT
C      PATIENT TO BMP

       IF (BUFFR(10) .EQ. 1) THEN
         CALL FILEM(13,BUFFR)
         J = J+1
       GOTO 23
       ENDIF

       BUFFR(2) = 22
       CALL FREE(8,1)
       XX(36)=XX(36)-1
       CALL EVENT(8)

       RETURN



C ******* RETEST PATIENT DISMISSAL FROM PP WARD *************

C      IF PATIENT HAS MET CONDITIONS FOR DEPARTURE, PATIENT CAN EXIT
C      SYSTEM PATIENT MUST 1) REMAIN LONG ENOUGH FOR RECOVERY OF STAY
C      AND 2) LEAVE BETWEEN WINDOW OF DEPARTURE BASED ON HOSPITAL POLICY
C      TO TEST PATIENT DEPARTURE, PULL FIRST PATIENT IN FILE AND TEST
```

```
C      CONDITIONS.  IF PATIENT FAILS CONDITIONS, REFILE UNTIL NEXT CHECK.

3        IF (NNQ(13) .EQ. 0) RETURN
         DO 300 J = 1,NNQ(13)


        CALL RMOVE(J,13,BUFFR)
        IF (TNOW .GE. BUFFR(12)) THEN
          IF (HR_CNT .GE. PP_R_M .AND. HR_CNT .LE. PP_R_E) THEN
             XX(36)=XX(36)-1
             BUFFR(2) = 22
             CALL FREE(8,1)
             CALL EVENT(8)
             CALL ENTER (3,BUFFR)
c            print *,'1: ******dismiss patient - enter network'
            RETURN
          ELSE
c           print *,'1: ********not between hours'
            CALL FILEM(13,BUFFR)
            RETURN
          ENDIF
        ELSE
          CALL FILEM(13,BUFFR)
c         print *,'1:  duration of stay not long enough'
          RETURN
        ENDIF
300   continue

      RETURN


C ****** DETERMINE HOUR OF DAY AND DAY OF WEEK **********


 4    IF (TNOW .LT. 1.) THEN
        HR_CNT = 24
        RETURN
      ELSE IF (TNOW .LT. 24.) THEN
        HR_CNT =AINT(TNOW)
        RETURN
      ELSE IF (TNOW .LT. 25.) THEN
        HR_CNT = 24
        DAY_CNT = DAY_CNT +1
        RETURN
      ELSE IF (TNOW .GE. 25.) THEN
        CNT = AMOD(TNOW,24.)
        HR_CNT=AINT(CNT)
        IF (HR_CNT .EQ. 0.) THEN
          HR_CNT = 24.
```

```
      IF (DAY_CNT .EQ. 7) THEN
        DAY_CNT = 1
      ELSE
        DAY_CNT = DAY_CNT + 1
      ENDIF
    ENDIF
    RETURN
  ENDIF

  RETURN


C**********FILE ARRIVAL OF NEW PP PATIENT*********

C     SEIZE POSTPARTUM BED FOR NEW ARRIVAL


  6   CALL SEIZE(8,1)
      CALL FILEM(13,ATRIB)

      RETURN


C*********CHECK STATUS OF L&D NURSE**********

C     EVERY TIME AN EVENT OCCURS THAT REQUIRES A L&D NURSE, EVENT 7 IS CHECKED
C     TO COUNT THE NUMBER OF L&D NURSES THAT ARE REQUIRED FOR THE ENTIRE SYSTEM.
C     NURSES ARE INCREMENTED/DECREMENTED TO MEET THE DEMAND.  RATIOS ARE FORMED
C     BASED ON GUIDELINES I.A.W. ACOG STANDARDS


7     DIFF = 0

      NUM_NRS = USERF(1)


C     NURSE EXCESS - FREE RESOURCE

      IF (NUM_NRS .LE. NRUSE(1)) THEN
        DIFF = NRUSE(1) - NUM_NRS
        IF (DIFF .LT. 1) THEN
          RETURN
        ELSE IF (DIFF .EQ. 1) THEN
           CALL FREE (1,1)
           RETURN
        ELSE IF (DIFF .GT.1) THEN
          OB_EXCS = AINT(DIFF)
          DO J = 1, OB_EXCS
```

```
          CALL FREE(1,1)
        END DO
        RETURN
      ENDIF

C     NURSE SHORTAGE - ADD TO RESOURCE

      ELSE IF (NUM_NRS .GT. NRUSE(1) .AND. NUM_NRS .GT. NNRSC(1)) THEN
        DIFF = NUM_NRS - NNRSC(1)
        OB_SLAK=ANINT(DIFF+.5)
        IF (NNRSC(1)-NRUSE(1) .EQ. 0) GOTO 200
        DO J = 1,NNRSC(1)-NRUSE(1)
          CALL SEIZE(1,1)
        END DO

200     IF (DIFF .LE. 1) THEN
          CALL ALTER (1,1)
          IF (NNRSC(1) .LE. 0) THEN
            CALL ERROR(1)
            RETURN
          ELSE
            CALL SEIZE(1,1)
            RETURN
          ENDIF
        ELSE IF (DIFF .GT. 1) THEN
          DO J = 1, OB_SLAK
            CALL ALTER(1,1)
          END DO
          DO J = 1,OB_SLAK
            IF (NNRSC(1) .LE. 0) THEN
              CALL ERROR(1)
              RETURN
            ELSE
              CALL SEIZE(1,1)
            ENDIF
          END DO
        ENDIF

      ELSE IF (NUM_NRS .GT. NRUSE(1)) THEN
        DIFF = NUM_NRS - NRUSE(1)
        IF (DIFF .LE. 1) THEN
          CALL SEIZE(1,1)
          RETURN
        ELSE IF (DIFF .GT. 1) THEN
          OB_SLAK=ANINT(DIFF+.5)
          DO J = 1,OB_SLAK
            CALL SEIZE(1,1)
          END DO
        ENDIF
      ENDIF
      RETURN
```

```
C*********CHECK STATUS OF PP NURSE**********

C     EVERY TIME AN EVENT OCCURS THAT REQUIRES A PP NURSE, EVENT 8 IS CHECKED
C     TO COUNT THE NUMBER OF PP NURSES THAT ARE REQUIRED FOR THE ENTIRE SYSTEM.
C     NURSES ARE INCREMENTED/DECREMENTED TO MEET THE DEMAND.  RATIOS ARE FORMED
C     I.A.W. ACOG STANDARDS


 8    DIFF = 0

      NUM_NRS = USERF(3)

C     NURSE EXCESS - FREE RESOURCE
      IF (NUM_NRS .LE. NRUSE(2)) THEN
        DIFF = NRUSE(2) - NUM_NRS
        IF (DIFF .LT. 1) THEN
          RETURN
        ELSE IF (DIFF .EQ. 1) THEN
           CALL FREE (2,1)
           RETURN
        ELSE IF (DIFF .GT.1) THEN
          PP_EXCS = AINT(DIFF)
          DO J = 1, PP_EXCS
            CALL FREE(2,1)
          END DO
          RETURN
        ENDIF

C     NURSE SHORTAGE - ADD TO RESOURCE

      ELSE IF (NUM_NRS .GT. NRUSE(2) .AND. NUM_NRS .GT. NNRSC(2)) THEN
        DIFF = NUM_NRS - NNRSC(2)
        PP_SLAK=ANINT(DIFF+.5)
        IF (NNRSC(2)-NRUSE(2) .EQ. 0) GOTO 250
        DO J = 1,NNRSC(2)-NRUSE(2)
          CALL SEIZE(2,1)
        END DO

250     IF (DIFF .LE. 1) THEN
          CALL ALTER (2,1)
          IF (NNRSC(2) .LE. 0) THEN
            CALL ERROR(1)
            RETURN
          ELSE
            CALL SEIZE(2,1)
            RETURN
          ENDIF
        ELSE IF (DIFF .GT. 1) THEN
```

```
        DO J = 1, PP_SLAK
          CALL ALTER(2,1)
        END DO
        DO J = 1,PP_SLAK
          IF (NNRSC(2) .LE. 0) THEN
            CALL ERROR(1)
            RETURN
          ELSE
            CALL SEIZE(2,1)
          ENDIF
        END DO
      ENDIF

    ELSE IF (NUM_NRS .GT. NRUSE(2)) THEN
      DIFF = NUM_NRS - NRUSE(2)
      IF (DIFF .LE. 1) THEN
        CALL SEIZE(2,1)
        RETURN
      ELSE IF (DIFF .GT. 1) THEN
        PP_SLAK=ANINT(DIFF+.5)
        DO J = 1,PP_SLAK
          CALL SEIZE(2,1)
        END DO
      ENDIF

    ENDIF
    RETURN


C*********CHECK STATUS OF AP NURSE****** ***

C     EVERY TIME AN EVENT OCCURS THAT REQUIRES A AP NURSE, EVENT 8 IS CHECKED
C     TO COUNT THE NUMBER OF AP NURSES THAT ARE REQUIRED FOR THE ENTIRE SYSTEM.
C     NURSES ARE INCREMENTED/DECREMENTED TO MEET THE DEMAND.  RATIOS ARE FORMED
C     I.A.W. ACOG STANDARDS


 9    DIFF = 0

      NUM_NRS = USERF(2)

C     NURSE EXCESS - FREE RESOURCE

      IF (NUM_NRS .LE. NRUSE(3)) THEN
        DIFF = NRUSE(3) - NUM_NRS
        IF (DIFF .LT. 1) THEN
          RETURN
        ELSE IF (DIFF .EQ. 1) THEN
           CALL F..E (3,1)
```

```
          RETURN
        ELSE IF (DIFF .GT.1) THEN
          AP_EXCS = AINT(DIFF)
          DO J = 1, AP_EXCS
            CALL FREE(3,1)
          END DO
          RETURN
        ENDIF

C     NURSE SHORTAGE - ADD TO RESOURCE

      ELSE IF (NUM_NRS .GT. NRUSE(3) .AND. NUM_NRS .GT. NNRSC(3)) THEN
        DIFF = NUM_NRS - NNRSC(3)
        AP_SLAK=ANINT(DIFF+.5)
        IF (NNRSC(3)-NRUSE(3) .EQ. 0) GOTO 295
        DO J = 1,NNRSC(3)-NRUSE(3)
          CALL SEIZE(3,1)
        END DO

295     IF (DIFF .LE. 1) THEN
          CALL ALTER (3,1)
          IF (NNRSC(3) .LE. 0) THEN
             CALL ERROR(1)
            RETURN
          ELSE
            CALL SEIZE(3,1)
            RETURN
          ENDIF
        ELSE IF (DIFF .GT. 1) THEN
          DO J = 1, AP_SLAK
            CALL ALTER(3,1)
          END DO
          DO J = 1,AP_SLAK
            IF (NNRSC(3) .LE. 0) THEN
              CALL ERROR(1)
              RETURN
            ELSE
              CALL SEIZE(3,1)
            ENDIF
          END DO
        ENDIF

      ELSE IF (NUM_NRS .GT. NRUSE(3)) THEN
        DIFF = NUM_NRS - NRUSE(3)
        IF (DIFF .LE. 1) THEN
          CALL SEIZE(3,1)
          RETURN
        ELSE IF (DIFF .GT. 1) THEN
          AP_SLAK=ANINT(DIFF+.5)
          DO J = 1,AP_SLAK
            CALL SEIZE(3,1)
```

```
          END DO
        ENDIF

      ENDIF
      RETURN


*********FIIE NEW PATIENT ARRIVAL TO PP WARD*********


10    CALL FILEM(13,ATRIB)
      RETURN


*********STO. ~ NURSE ARRAYS*************************

C     GENERATE FREQUENCY DISTRIBUTIONS BY HOUR & DAY


11    IF (HR_CNT  EQ. 0) RETURN

      NOB_HR(HR_CNT) = ST_OBHR
      NAP_HR(HR_CNT) = ST_APHR
      NPP_HR(HR_CNT) = ST_PPHR


      DO J=1,3
        IF (J .EQ. 1) THEN
          STORE_A(3*HR_CNT-2)=DAY_CNT
        ENDIF
        IF (J .EQ. 2) THEN
          STORE_A(3*HR_CNT-1)=HR_CNT
        ENDIF
        IF (J .EQ. 3) THEN
          STORE_A(3*HR_CNT)=NOB_HR(HR_CNT)
          STORE_B(3*HR_CNT)=NAP_HR(HR_CNT)
          STORE_C(3*HR_CNT)=NPP_HR(HR_CNT)
        ENDIF
      END DO


C     WRITE TO FILE ON THE 12TH AND 24TH HOUR


      IF (HR_CNT .EQ.12) THEN

C     WRITE TO L&D

        WRITE(26,514) STORE_A(1),STORE_A(2),STORE_A(3),STORE_A(4),
```

```
     *  STORE_A(5),STORE_A(6),STORE_A(7),STORE_A(8),STORE_A(9),
     *  STORE_A(10),STORE_A(11),STORE_A(12),STORE_A(13),STORE_A(14),
     *  STORE_A(15),STORE_A(16),STORE_A(17),STORE_A(18),STORE_A(19),
     *  STORE_A(20),STORE_A(21),STORE_A(22),STORE_A(23),STORE_A(24),
     *  STORE_A(25),STORE_A(26),STORE_A(27),STORE_A(28),STORE_A(29),
     *  STORE_A(30),STORE_A(31),STORE_A(32),STORE_A(33),STORE_A(34),
     *  STORE_A(35),STORE_A(36)

C     WRITE TO AP

       WRITE(27,514) STORE_A(1),STORE_A(2),STORE_B(3),STORE_A(4),
     *  STORE_A(5),STORE_B(6),STORE_A(7),STORE_A(8),STORE_B(9),
     *  STORE_A(10),STORE_A(11),STORE_B(12),STORE_A(13),STORE_A(14),
     *  STORE_B(15),STORE_A(16),STORE_A(17),STORE_B(18),STORE_A(19),
     *  STORE_A(20),STORE_B(21),STORE_A(22),STORE_A(23),STORE_B(24),
     *  STORE_A(25),STORE_A(26),STORE_B(27),STORE_A(28),STORE_A(29),
     *  STORE_B(30),STORE_A(31),STORE_A(32),STORE_B(33),STORE_A(34),
     *  STORE_A(35),STORE_B(36)

C     WRITE TO PP

       WRITE(28,514) STORE_A(1),STORE_A(2),STORE_C(3),STORE_A(4),
     *  STORE_A(5),STORE_C(6),STORE_A(7),STORE_A(8),STORE_C(9),
     *  STORE_A(10),STORE_A(11),STORE_C(12),STORE_A(13),STORE_A(14),
     *  STORE_C(15),STORE_A(16),STORE_A(17),STORE_C(18),STORE_A(19),
     *  STORE_A(20),STORE_C(21),STORE_A(22),STORE_A(23),STORE_C(24),
     *  STORE_A(25),STORE_A(26),STORE_C(27),STORE_A(28),STORE_A(29),
     *  STORE_C(30),STORE_A(31),STORE_A(32),STORE_C(33),STORE_A(34),
     *  STORE_A(35),STORE_C(36)

      ENDIF


      IF (HR_CNT .EQ. 24) THEN

C     WRITE TO LAD

       WRITE(26,514) STORE_A(37),STORE_A(38),STORE_A(39),STORE_A(40),
     *  STORE_A(41),STORE_A(42),STORE_A(43),STORE_A(44),STORE_A(45),
     *  STORE_A(46),STORE_A(47),STORE_A(48),STORE_A(49),STORE_A(50),
     *  STORE_A(51),STORE_A(52),STORE_A(53),STORE_A(54),STORE_A(55),
     *  STORE_A(56),STORE_A(57),STORE_A(58),STORE_A(59),STORE_A(60),
     *  STORE_A(61),STORE_A(62),STORE_A(63),STORE_A(64),STORE_A(65),
     *  STORE_A(66),STORE_A(67),STORE_A(68),STORE_A(69),STORE_A(70),
     *  STORE_A(71),STORE_A(72)

C     WRITE TO AP

       WRITE(27,514) STORE_A(37),STORE_A(38),STORE_B(39),STORE_A(40),
     *  STORE_A(41),STORE_B(42),STORE_A(43),STORE_A(44),STORE_B(45),
     *  STORE_A(46),STORE_A(47),STORE_B(48),STORE_A(49),STORE_A(50),
```

```
     *    STORE_B(51),STORE_A(52),STORE_A(53),STORE_B(54),STORE_A(55),
     *    STORE_A(56),STORE_B(57),STORE_A(58),STORE_A(59),STORE_B(60),
     *    STORE_A(61),STORE_A(62),STORE_B(63),STORE_A(64),STORE_A(65),
     *    STORE_B(66),STORE_A(67),STORE_A(68),STORE_B(69),STORE_A(70),
     *    STORE_A(71),STORE_B(72)

C      WRITE TO PP

          WRITE(28,514) STORE_A(37),STORE_A(38),STORE_C(39),STORE_A(40),
     *    STORE_A(41),STORE_C(42),STORE_A(43),STORE_A(44),STORE_C(45),
     *    STORE_A(46),STORE_A(47),STORE_C(48),STORE_A(49),STORE_A(50),
     *    STORE_C(51),STORE_A(52),STORE_A(53),STORE_C(54),STORE_A(55),
     *    STORE_A(56),STORE_C(57),STORE_A(58),STORE_A(59),STORE_C(60),
     *    STORE_A(61),STORE_A(62),STORE_C(63),STORE_A(64),STORE_A(65),
     *    STORE_C(66),STORE_A(67),STORE_A(68),STORE_C(69),STORE_A(70),
     *    STORE_A(71),STORE_C(72)

        ENDIF

514         FORMAT(1X,F5.1,1X,F5.1,1X,F5.1,1X,F5.1,1X,F5.1,1X,F5.1,1X,
     *        F5.1,1X,F5.1,1X,F5.1,1X,F5.1,1X,F5.1,1X,F5.1,1X,F5.1,1X,
     *        F5.1,1X,F5.1,1X,F5.1,1X,F5.1,1X,F5.1,1X,F5.1,1X,F5.1,1X,
     *        F5.1,1X,F5.1,1X,F5.1,1X,F5.1,
     *        1X,F5.1,1X,F5.1,1X,F5.1,1X,F5.1,1X,F5.1,1X,F5.1,1X,
     *        F5.1,1X,F5.1,1X,F5.1,1X,F5.1,1X,F5.1,1X,F5.1)

C      RESET HIGHEST NURSE REQUIREMENT BACK TO ZERO

       ST_OBHR = 0
       ST_APHR = 0
       ST_PPHR = 0

       ENDIF

       RETURN

C *************SCHEDULE INPATIENT ARRIVALS TO  SYSTEM ***********

C      INPATIENT ARRIVAL OCCURS ON DAY OF SURGERY AND DURING DUTY HRS
C      DETERMINE LENGTH OF PATIENT WAIT.  WAIT DEPENDS ON DAY OF SURGERY
C      AND DAY PATIENT APPROACHES SYSTEM.  (INPATIENT DOES NOT WAIT IN
```

```
C     SYSTEM.  STORE WAITING PERIOD (EXTERNAL TO SYSTEM)

12    IF (SURG_DY .GE. DAY_CNT) THEN
        DIFF_DAY=SURG_DY-DAY_CNT
        IF (DIFF_DAY .EQ. 0) THEN
          IF (PAT_ARR .LT. T_IN_M) THEN
            P_WAIT= T_IN_M - PAT_ARR
            NUM_OBS=NUM_OBS+1
            SUM_WT = SUM_WT + P_WAIT
            RETURN
          ELSE IF ((PAT_ARR .GE. T_IN_M) .AND. (PAT_ARR .LE. T_IN_E)) THEN
c             print *,'gate is open'
            P_WAIT = 0
            NUM_OBS=NUM_OBS+1
            SUM_WT = SUM_WT + P_WAIT
             RETURN
          ELSE IF (PAT_ARR .GT. T_IN_E) THEN
c             print *,'gate is closed'
             P_WAIT = 7*24-(PAT_ARR-T_IN_M)
            NUM_OBS=NUM_OBS+1
            SUM_WT = SUM_WT + P_WAIT

            RETURN
          ENDIF
        ELSE IF (DIFF_DAY .GT. 0) THEN
          IF (PAT_ARR .LT. T_IN_M) THEN
            P_WAIT= (DIFF_DAY*24) + T_IN_M - PAT_ARR
            NUM_OBS=NUM_OBS+1
            SUM_WT = SUM_WT + P_WAIT
            RETURN
          ELSE IF ((PAT_ARR .GE. T_IN_M) .AND. (PAT_ARR .LE. T_IN_E)) THEN
c             print *,'gate is open'
             P_WAIT = (DIFF_DAY*24) - (PAT_ARR - T_IN_M)
            NUM_OBS=NUM_OBS+1
            SUM_WT = SUM_WT + P_WAIT
             RETURN
          ELSE IF (PAT_ARR .GT. T_IN_E) THEN
c             print *,'gate is closed'
            P_WAIT = (DIFF_DAY*24) - (PAT_ARR-T_IN_M)
            SUM_WT = SUM_WT + P_WAIT
            NUM_OBS=NUM_OBS+1
             RETURN
          ENDIF
        ENDIF
      ELSE IF (SURG_DY .LT. DAY_CNT) THEN
c       PRINT *,'TESTDAY LT DAY'
        DIFF_DAY= 7 - (DAY_CNT - SURG_DY)
        IF (PAT_ARR .LT. T_IN_M) THEN
        P_WAIT=(DIFF_DAY*24) + (T_IN_M - PAT_ARR)
          NUM_OBS=NUM_OBS+1
```

```
          SUM_WT = SUM_WT + P_WAIT
          RETURN
        ELSE IF ((PAT_ARR .GE. T_IN_M) .AND. (PAT_ARR .LE. T_IN_E)) THEN
c         print *,'gate is open'
          P_WAIT = (DIFF_DAY*24) - (PAT_ARR - T_IN_M)
          NUM_OBS=NUM_OBS+1
          SUM_WT = SUM_WT + P_WAIT
          RETURN
        ELSE IF (PAT_ARR .GT. T_IN_E) THEN
c         print *,'gate is closed'
          P_WAIT = (DIFF_DAY*24) - (PAT_ARR - T_IN_M)
          NUM_OBS=NUM_OBS+1
          SUM_WT = SUM_WT + P_WAIT
          RETURN
        ENDIF
      ENDIF

      RETURN



      END




      FUNCTION USERF(I)

      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

      COMMON/UCOM1/NOB_HR(24),NOB_DAY(7),NAP_HR(24),NAP_DAY(7),
     *NPP_HR(24),NPP_DAY(7)

      REAL DIFF_DAY

      EQUIVALENCE (XX(22),ST_OBHR),(XX(24),ST_APHR),(XX(26),ST_PPHR)


C     ATTRIBUTES

      EQUIVALENCE (ATRIB(2),PAT_LOC),

      USERF=0

      GO TO (1,2,3), I

      WRITE(6,*) ' ERROR NUMBERING OF EVENTS'


C *******FIND L&D NURSE REQUIREMENT******
```

```
1    IF ((PAT_LOC .EQ. 6) .OR. (PAT_LOC .EQ. 11) .OR.
    * (PAT_LOC .EQ. 19)) THEN

       USERF = (NNACT(1)+NNACT(13) + NNACT(20))/6.
    *          + (NNACT(2)+NNACT(3)+NNACT(8)+NNACT(9)+ NNACT(17))/2.
    *          + (NNACT(4)+NNACT(5)+NNACT(7))/1.


     ELSE IF ((PAT_LOC .EQ. 4) .OR. (PAT_LOC .EQ. 5) .OR.
    *    (PAT_LOC .EQ. 7)) THEN

       USERF = (NNACT(1)+NNACT(13) + NNACT(20))/6.
    *          + (NNACT(2)+NNACT(3)+NNACT(8)+NNACT(9)+ NNACT(17))/2.
    *          + (NNACT(4)+NNACT(5)+NNACT(7))/1. + 1.


     ELSE IF ((PAT_LOC .EQ. 2) .OR. (PAT_LOC .EQ. 3) .OR.
    *  (PAT_LOC .EQ. 8) .OR. (PAT_LOC .EQ. 9) .OR.
    *  (PAT_LOC .EQ. 17)) THEN

       USERF = (NNACT(1)+NNACT(13) + NNACT(20))/6.
    *   +(NNACT(2)+NNACT(3)+NNACT(8)+NNACT(9)+NNACT(17))/2.+(1./2.)
    *   + (NNACT(4)+NNACT(5)+NNACT(7))/1.


     ELSE IF ((PAT_LOC .EQ. 1) .OR. (PAT_LOC .EQ. 10) .OR.
    *  (PAT_LOC .EQ. 13) .OR. (PAT_LOC .EQ. 20)) THEN

       USERF =(NNACT(1)+NNACT(10)+NNACT(13)+NNACT(20))/6.+(1./6.)
    *        + (NNACT(2)+NNACT(3)+NNACT(8)+NNACT(9)+ NNACT(17))/2.
    *        + (NNACT(4)+NNACT(5)+NNACT(7))/1.

C      FIND HIGHEST L&D NURSE RQMT FOR EACH HOUR

       IF (USERF .GT. ST_OBHR) THEN
         ST_OBHR = ANINT(USERF+.5)
       ENDIF

       RETURN

     ENDIF



C*****FIND ANTEPARTUM NURSE******
```

```
 2    IF (PAT_LOC .EQ. 16) THEN

        USERF = (NNACT(14))/6.

      ELSE IF (PAT_LOC .EQ. 14) THEN

        USERF = (NNACT(14))/6. + (1./6.)

C     FIND HIGHEST AP NURSE RQMT FOR EACH HOUR

        IF (USERF .GT. ST_APHR) THEN
          ST_APHR = ANINT(USERF+.5)
        ENDIF

        RETURN

      ENDIF


C     FIND POSTPARTUM NURSE

3     IF ((PAT_LOC .EQ. 22)) THEN

        USERF = NRUSE(8)/6.

      ELSE IF ((PAT_LOC .EQ. 12) .OR. (PAT_LOC .EQ. 15) .OR.
     *(PAT_LOC .EQ. 18)) THEN

        USERF = NRUSE(8)/6. + (1./6.)

C     FIND HIGHEST PP NURSE RQMT FOR EACH HOUR

        IF (USERF .GT. ST_PPHR) THEN
          ST_PPHR = ANINT(USERF+.5)
        ENDIF

        RETURN

      ENDIF

      END


      SUBROUTINE ALLOC(I,IFLAG)


      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
```

```
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

      IFLAG = 0

      GO TO  (1,2,3,4,5,6,7), I

      WRITE(6,*) ' ERROR NUMBERING OF EVENTS'

C     ASSIGN EXAM ROOM

1     IF (NNRSC(4) .LE .0) THEN
        RETURN
      ELSE
        CALL SEIZE (4,1)
        IFLAG=-1
        RETURN
      ENDIF

C     ASSIGN LABOR ROOM

2     IF (NNRSC(5) .LE .0) THEN
        RETURN
      ELSE
        CALL SEIZE (5,1)
        IFLAG=-1
        RETURN
      ENDIF

C     ASSIGN DELIVERY ROOM

3     IF (NNRSC(6) .LE .0) THEN
        RETURN
      ELSE
        CALL SEIZE (6,1)
        RETURN
      ENDIF

C     ASSIGN RECOVERY ROOM

4     IF (NNRSC(7) .LE .0) THEN
        RETURN
      ELSE
        CALL SEIZE (7,1)
        IFLAG=-1
        RETURN
```

```
      ENDIF

C     ASSIGN POSTPARTUM ROOM

 5    IF (NNRSC(8) .LE .0) THEN
        RETURN
      ELSE
        CALL SEIZE (8,1)
        IFLAG=-1
        RETURN
      ENDIF

C     ASSIGN ANTEPARTUM ROOM

 6    IF (NNRSC(9) .LE .0) THEN
        RETURN
      ELSE
        CALL SEIZE (9,1)
        IFLAG=-1
        RETURN
      ENDIF

C     PATIENT WAITS FOR SCHEDULED DAY OF INPATIENT TEST

7     IF (NNRSC(6) .LE .0) THEN
        RETURN
      ELSE
        IF (NNQ(14) .GT. 0) THEN
            RETURN
        ENDIF
        CALL SEIZE (6,1)
        IFLAG=-1
        RETURN
      ENDIF

      END

      SUBROUTINE OTPUT

      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

C     COLLECT ON PARAMETERS OF INTEREST

       UTE_LD=RRAVG(1)
```

```
      CALL COLCT(UTE_LD,1)
      PPN_UT=RRAVG(2)
      CALL COLCT(PPN_UT,2)
      APN_UT=RRAVG(3)
      CALL COLCT(APN_UT,3)
      EXAM_UT=RRAVG(4)
      CALL COLCT(EXAM_UT,4)
      UT_LABR=RRAVG(5)
      CALL COLCT(UT_LABR,5)
      DLVR_UT=RRAVG(6)
      CALL COLCT(DLVR_UT,6)
      RCVR_UT=RRAVG(7)
      CALL COLCT(RCVR_UT,7)
      PPR_UT=RRAVG(8)
      CALL COLCT(PPR_UT,8)
      APEX_UT=RRAVG(9)
      CALL COLCT(APEX_UT,9)

C     COLLECT WAITING TIMES FOR RESOURCES

      EXAM_FL=FFAWT(4)
      CALL COLCT(EXAM_FL,10)
      LABR_FL=FFAWT(5)
      CALL COLCT(LABR_FL,11)
      DLVR1FL=FFAWT(6)
      CALL COLCT(DLVR1FL,12)
      DLVR2FL=FFAWT(14)
      CALL COLCT(DLVR2FL,13)
      RCVR_FL=FFAWT(7)
      CALL COLCT(RCVR_FL,14)
      PPR_FL=FFAWT(8)
      CALL COLCT(PPR_FL,15)
      APEX_FL=FFAWT(9)
      CALL COLCT(APEX_FL,16)
      S_C_FL=FFAWT(10)
      CALL COLCT(S_C_FL,17)
      OUTP_FL=FFAWT(11)
      CALL COLCT(OUTP_FL,18)

      PAT_INF=FFAWT(12)
      CALL COLCT(PAT_INF,19)

      AVGAV=RRAVA(1)
      CALL COLCT(AVGAV,21)
      CHNG=RRAVG(1)
      CALL COLCT(CHNG,22)
      DEV=RRAVG(1)
      CALL COLCT(DEV,23)

      PPAVG=FFAVG(13)
      CALL COLCT(PPAVG,24)
```

```
      PPWAIT=FFAWT(13)
      CALL COLCT(PPWAIT,25)
      STNDDEV=FFMAX(13)
      CALL COLCT(STNDDEV,26)

      AVG_BMP=CCAVG(27)
      CALL COLCT(AVG_BMP,28)
      BMP_NUM=CCNUM(27)
      CALL COLCT(BMP_NUM,29)

      S_D_EX=RRSTD(4)
      CALL COLCT(S_D_EX,30)
      S_D_LR=RRSTD(5)
      CALL COLCT(S_D_LR,31)
      S_D_DR=RRSTD(6)
      CALL COLCT(S_D_DR,32)
      S_D_RR=RRSTD(7)
      CALL COLCT(S_D_RR,33)
      S_D_PPR=RRSTD(8)
      CALL COLCT(S_D_PPR,34)
      S_D_APR=RRSTD(9)
      CALL COLCT(S_D_APR,35)

     RETURN

     END
```

Appendix E.

WPAFB Input Parameters

The following output provides an example of the values that are required before output can be obt

```
VAG_D1 = 51.
UC_D1 = 20.
SC_D1 = 10.
PAT_I1 = 8.
FALSE_1 = 90.
NBIRTH = 81
PCT_VAG = .629
PCT_UC = .247
PCT_SC = .123
OUTPNT = 90.
NLABORR = 6.
NDLVRYR = 3.
NEXAMR = 3.
NPPBEDR = 18.
NRCVRYR = 4.
NAPEXMR = 1.
PP_R_M = 7
PP_R_E = 20
P_SC_M = .5
P_SC_T = .5
P_IN_M = .2
P_IN_T = .2
P_IN_W = .2
P_IN_TH = .2
P_IN_F = .2
P_OUT_M = .2
P_OUT_T = .2
P_OUT_W = .2
P_OUTTH = .2
P_OUT_F = .2
T_SC_M = 8
T_SC_E = 10
T_IN_M = 8
T_IN_E = 12
T_OUT_M = 8
T_OUT_E = 16
DUR_CES = 72
DUR_INP = 72
DUR_VAG = 24
```

S L A M I I S U M M A R Y R E P O R T

SIMULATION PROJECT THESIS BY STEPHENS

DATE 11/25/1992 RUN NUMBER 1 OF 1

CURRENT TIME 0.1780E+05
STATISTICAL ARRAYS CLEARED AT TIME 0.1000E+04

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
L & D NURSE UTE	0.719E+00	0.000E+00	0.000E+00	0.719E+00	0.719E+00	1
PP NURSE UTE	0.770E+00	0.000E+00	0.000E+00	0.770E+00	0.770E+00	1
AP NURSE UTE	0.243E-01	0.000E+00	0.000E+00	0.243E-01	0.243E-01	1
EXAM ROOM UTE	0.695E-01	0.000E+00	0.000E+00	0.695E-01	0.695E-01	1
LABOR ROOM UTE	0.576E+00	0.000E+00	0.000E+00	0.576E+00	0.576E+00	1
DELVRY ROOM UTE	0.136E+00	0.000E+00	0.000E+00	0.136E+00	0.136E+00	1
RECVRY ROOM UTE	0.405E-01	0.000E+00	0.000E+00	0.405E-01	0.405E-01	1
PP ROOM UTE	0.575E+01	0.000E+00	0.000E+00	0.575E+01	0.575E+01	1
AP ROOM UTE	0.592E-01	0.000E+00	0.000E+00	0.592E-01	0.592E-01	1
AVG WAIT EXAM	0.000E+00	0.000E+00	0.100E+05	0.000E+00	0.000E+00	1
AVG WAIT LABOR	0.000E+00	0.000E+00	0.100E+05	0.000E+00	0.000E+00	1
AVG WAIT DLVRY1	0.262E-01	0.000E+00	0.000E+00	0.262E-01	0.262E-01	1
AVG WAIT DLVRY2	0.304E+00	0.000E+00	0.000E+00	0.304E+00	0.304E+00	1
AVG WAIT RCVRY	0.000E+00	0.000E+00	0.100E+05	0.000E+00	0.000E+00	1
AVG WAIT PPBED	0.000E+00	0.000E+00	0.100E+05	0.000E+00	0.000E+00	1
AVG WAIT APEXM	0.955E+00	0.000E+00	0.000E+00	0.955E+00	0.955E+00	1
AVG SCH.C WAIT	0.591E+02	0.000E+00	0.000E+00	0.591E+02	0.591E+02	1
AVG OUTPT WAIT	0.156E+02	0.000E+00	0.000E+00	0.156E+02	0.156E+02	1
AVG INPAT WAIT	0.300E+02	0.000E+00	0.000E+00	0.150E+02	0.150E+02	1
AVAIL LDN	0.794E+01	0.000E+00	0.000E+00	0.794E+01	0.794E+01	1
LDN CHANGED	0.719E+00	0.000E+00	0.000E+00	0.719E+00	0.719E+00	1
STNDDEV	0.719E+00	0.000E+00	0.000E+00	0.719E+00	0.719E+00	1
AVG # IN PP	0.575E+01	0.000E+00	0.000E+00	0.575E+01	0.575E+01	1
AVG WAIT IN PP	0.580E+01	0.000E+00	0.000E+00	0.580E+01	0.580E+01	1
MAX IN PP	0.180E+02	0.000E+00	0.000E+00	0.180E+02	0.180E+02	1
BMP TME			NO VALUES RECORDED			
AVG BMP TME	0.000E+00	0.000E+00	0.100E+05	0.000E+00	0.000E+00	1
AVG NUM BMPD	0.000E+00	0.000E+00	0.100E+05	0.000E+00	0.000E+00	1
S_D EXAM	0.263E+00	0.000E+00	0.000E+00	0.263E+00	0.263E+00	1

S_D LABR	0.755E+00	0.000E+00	0.000E+00	0.755E+00	0.755E+00	1
S_D DLVRY	0.422E+00	0.000E+00	0.000E+00	0.422E+00	0.422E+00	1
S_D RCVRY	0.228E+00	0.000E+00	0.000E+00	0.228E+00	0.228E+00	1
S_D PP ROOM	0.294E+01	0.000E+00	0.000E+00	0.294E+01	0.294E+01	1
S_D AP ROOM	0.236E+00	0.000E+00	0.000E+00	0.236E+00	0.236E+00	1

FILE STATISTICS

FILE NUMBER	LABEL/TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAIT TIME
1	CRANE	0.000	0.000	0	0	0.000
2	CRANE	0.000	0.000	0	0	0.000
3	CRANE	0.000	0.000	0	0	0.000
4	INTL AWAIT	0.000	0.000	1	0	0.000
5	AWAIT	0.000	0.000	1	0	0.000
6	AWAIT	0.003	0.076	3	0	0.026
7	AWAIT	0.000	0.000	1	0	0.000
8	AWAIT	0.000	0.000	1	0	0.000
9	AWAIT	0.116	0.776	16	0	0.955
10	AWAIT	0.858	1.142	6	2	59.098
11	AWAIT	1.893	2.596	17	3	15.561
12		0.000	0.000	0	0	0.000
13		5.749	2.940	18	3	5.799
14	AWAIT	0.003	0.072	4	0	0.304
15		0.000	0.000	0	0	0.000
16		0.000	0.000	0	0	0.000
17		0.000	0.000	0	0	0.000
18		0.000	0.000	0	0	0.000
19		0.000	0.000	0	0	0.000
20		0.000	0.000	0	0	0.000
21	CALENDAR	13.492	1.861	38	13	1.007

REGULAR ACTIVITY STATISTICS

ACTIVITY INDEX/LABEL	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL	ENTITY COUNT
1 CHECK DILATI	0.0329	0.1821	3	0	3684
3 ACTIVE LABOR	0.2457	0.4876	4	0	1183
4 STAGE 2 DURA	0.0429	0.2049	2	0	1183
5 STAGE 3 DURA	0.0155	0.1242	2	0	1183
6 CESAREANS MO	0.0405	0.2278	3	0	681
7 CS OPERATION	0.0607	0.2904	3	0	681
8 HALT LABOR	0.0833	0.2889	2	0	188
9 DYSTOCIA 2 H	0.0175	0.1334	2	0	147
10 RECOVERY DUR	0.2511	0.5118	5	0	1864
13 PATIENT REMA	0.1839	0.4299	5	0	2062

14 OUTPATIENT T	0.0592	0.2361	1	0	2041
18 SCHD C-S PAT	0.3457	0.9257	6	0	242
20 DURATION OF	0.0366	0.1909	3	0	4092
21	0.5163	0.7613	4	1	108
22	0.3435	0.6026	3	0	77
23	0.0000	0.0000	0	0	0
24	0.0000	0.0000	0	0	0
25	0.0000	0.0000	0	0	0

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	OBNURSE	9	0.72	0.640	5	1
2	PPNURSE	5	0.77	0.838	[illegible]	0
3	APNURSE	1	0.02	0.154	1	0
4	EXAMR	3	0.07	0.263	3	0
5	LABORR	6	0.58	0.755	6	0
6	DLVRYR	3	0.14	0.422	3	0
7	RCVRYR	4	0.04	0.228	3	0
8	PPBEDR	18	5.75	2.940	18	3
9	APEXMR	1	0.06	0.236	1	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	OBNURSE	8	7.9401	4	9
2	PPNURSE	5	4.2294	2	5
3	APNURSE	1	0.9756	0	1
4	EXAMR	3	2.9305	0	3
5	LABORR	6	5.4235	0	6
6	DLVRYR	3	2.8641	0	3
7	RCVRYR	4	3.9594	1	4
8	PPBEDR	15	12.2500	0	18
9	APEXMR	1	0.9406	0	1

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	SCHDL_C	CLOSED	0.0238
2	OUT_PAT	CLOSED	0.2381

Appendix F.

SAS Output

TABLE OF HOUR BY NURSE

HOUR	NURSE: Frequency / Percent / Row Pct / Col Pct	0	1	2	3	Total
1	Frequency	492	167	74	8	742
	Percent	2.76	0.94	0.42	0.04	4.17
	Row Pct	66.31	22.51	9.97	1.08	
	Col Pct	4.31	4.12	3.72	3.39	
2	Frequency	475	174	84	9	742
	Percent	2.67	0.98	0.47	0.05	4.17
	Row Pct	64.02	23.45	11.32	1.21	
	Col Pct	4.16	4.29	4.22	3.81	
Total		11409	4057	1989	236	17796
		64.11	22.80	11.18	1.33	100.00

TABLE OF HOUR BY NURSE

HOUR	NURSE: Frequency / Percent / Row Pct / Col Pct	0	1	2	3	Total
3	Frequency	474	176	85	7	742
	Percent	2.66	0.99	0.48	0.04	4.17
	Row Pct	63.88	23.72	11.46	0.94	
	Col Pct	4.15	4.34	4.27	2.97	
4	Frequency	488	165	84	5	742
	Percent	2.74	0.93	0.47	0.03	4.17
	Row Pct	65.77	22.24	11.32	0.67	
	Col Pct	4.28	4.07	4.22	2.12	
Total		11409	4057	1989	236	17796
		64.11	22.80	11.18	1.33	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

Frequency / Percent / Row Pct / Col Pct	0	1	2	3	Total
5	502	176	60	4	742
	2.82	0.99	0.34	0.02	4.17
	67.65	23.72	8.09	0.54	
	4.40	4.34	3.02	1.69	
6	500	148	89	5	742
	2.81	0.83	0.50	0.03	4.17
	67.39	19.95	11.99	0.67	
	4.38	3.65	4.47	2.12	
Total	11409	4057	1989	236	17796
	64.11	22.80	11.18	1.33	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

Frequency / Percent / Row Pct / Col Pct	0	1	2	3	Total
7	499	168	66	9	742
	2.80	0.94	0.37	0.05	4.17
	67.25	22.64	8.89	1.21	
	4.37	4.14	3.32	3.81	
8	394	169	116	21	742
	2.21	0.95	0.65	0.12	4.17
	53.10	22.78	15.63	2.83	
	3.45	4.17	5.83	8.90	
Total	11409	4057	1989	236	17796
	64.11	22.80	11.18	1.33	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

HOUR	Frequency / Percent / Row Pct / Col Pct	NURSE 0	1	2	3	Total
9	Frequency	464	145	85	24	742
	Percent	2.61	0.81	0.48	0.13	4.17
	Row Pct	62.53	19.54	11.46	3.23	
	Col Pct	4.07	3.57	4.27	10.17	
10	Frequency	411	159	113	29	742
	Percent	2.31	0.89	0.63	0.16	4.17
	Row Pct	55.39	21.43	15.23	3.91	
	Col Pct	3.60	3.92	5.68	12.29	
Total		11409	4057	1989	236	17796
		64.11	22.80	11.18	1.33	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

HOUR	Frequency / Percent / Row Pct / Col Pct	NURSE 0	1	2	3	Total
11	Frequency	465	175	83	16	742
	Percent	2.61	0.98	0.47	0.09	4.17
	Row Pct	62.67	23.58	11.19	2.16	
	Col Pct	4.08	4.31	4.17	6.78	
12	Frequency	464	175	93	10	742
	Percent	2.61	0.98	0.52	0.06	4.17
	Row Pct	62.53	23.58	12.53	1.35	
	Col Pct	4.07	4.31	4.68	4.24	
Total		11409	4057	1989	236	17796
		64.11	22.80	11.18	1.33	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

Frequency / Percent / Row Pct / Col Pct	0	1	2	3	Total
13	496	163	72	9	741
	2.79	0.92	0.40	0.05	4.16
	66.94	22.00	9.72	1.21	
	4.35	4.02	3.62	3.81	
14	477	181	75	8	741
	2.68	1.02	0.42	0.04	4.16
	64.37	24.43	10.12	1.08	
	4.18	4.46	3.77	3.39	
Total	11409	4057	1989	236	17796
	64.11	22.80	11.18	1.33	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

Frequency / Percent / Row Pct / Col Pct	0	1	2	3	Total
15	474	180	78	9	741
	2.66	1.01	0.44	0.05	4.16
	63.97	24.29	10.53	1.21	
	4.15	4.44	3.92	3.81	
16	479	177	78	7	741
	2.69	0.99	0.44	0.04	4.16
	64.64	23.89	10.53	0.94	
	4.20	4.36	3.92	2.97	
Total	11409	4057	1989	236	17796
	64.11	22.80	11.18	1.33	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

Frequency / Percent / Row Pct / Col Pct	0	1	2	3	Total
17	499	159	74	9	741
	2.80	0.89	0.42	0.05	4.16
	67.34	21.46	9.99	1.21	
	4.37	3.92	3.72	3.81	
18	475	165	94	7	741
	2.67	0.93	0.53	0.04	4.16
	64.10	22.27	12.69	0.94	
	4.16	4.07	4.73	2.97	
Total	11409	4057	1989	236	17796
	64.11	22.80	11.18	1.33	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

Frequency / Percent / Row Pct / Col Pct	0	1	2	3	Total
19	480	175	76	10	741
	2.70	0.98	0.43	0.06	4.16
	64.78	23.62	10.26	1.35	
	4.21	4.31	3.82	4.24	
20	483	177	74	6	741
	2.71	0.99	0.42	0.03	4.16
	65.18	23.89	9.99	0.81	
	4.23	4.36	3.72	2.54	
Total	11409	4057	1989	236	17796
	64.11	22.80	11.18	1.33	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

Frequency / Percent / Row Pct / Col Pct	0	1	2	3	Total
21	466	178	92	5	741
	2.62	1.00	0.52	0.03	4.16
	62.89	24.02	12.42	0.67	
	4.08	4.39	4.63	2.12	
22	480	156	96	8	741
	2.70	0.88	0.54	0.04	4.16
	64.78	21.05	12.96	1.08	
	4.21	3.85	4.83	3.39	
Total	11409	4057	1989	236	17796
	64.11	22.80	11.18	1.33	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

Frequency / Percent / Row Pct / Col Pct	0	1	2	3	Total
23	493	174	65	7	741
	2.77	0.98	0.37	0.04	4.16
	66.53	23.48	8.77	0.94	
	4.32	4.29	3.27	2.97	
24	479	175	83	4	741
	2.69	0.98	0.47	0.02	4.16
	64.64	23.62	11.20	0.54	
	4.20	4.31	4.17	1.69	
Total	11409	4057	1989	236	17796
	64.11	22.80	11.18	1.33	100.00

TABLE OF HOUR BY NURSE

HOUR / NURSE Frequency Percent Row Pct Col Pct	4	5	6	Total
1	1 0.01 0.13 1.19	0 0.00 0.00 0.00	0 0.00 0.00 0.00	742 4.17
2	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	742 4.17
Total	84 0.47	19 0.11	2 0.01	17796 100.00

TABLE OF HOUR BY NURSE

HOUR / NURSE Frequency Percent Row Pct Col Pct	4	5	6	Total
3	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	742 4.17
4	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	742 4.17
Total	84 0.47	19 0.11	2 0.01	17796 100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

Frequency / Percent / Row Pct / Col Pct	4	5	6	Total
5	0	0	0	742
	0.00	0.00	0.00	4.17
	0.00	0.00	0.00	
	0.00	0.00	0.00	
6	0	0	0	742
	0.00	0.00	0.00	4.17
	0.00	0.00	0.00	
	0.00	0.00	0.00	
Total	84	19	2	17796
	0.47	0.11	0.01	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

Frequency / Percent / Row Pct / Col Pct	4	5	6	Total
7	0	0	0	742
	0.00	0.00	0.00	4.17
	0.00	0.00	0.00	
	0.00	0.00	0.00	
8	33	8	1	742
	0.19	0.04	0.01	4.17
	4.45	1.08	0.13	
	39.29	42.11	50.00	
Total	84	19	2	17796
	0.47	0.11	0.01	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

Frequency / Percent / Row Pct / Col Pct	4	5	6	Total
9	16	7	1	742
	0.09	0.04	0.01	4.17
	2.16	0.94	0.13	
	19.05	36.84	50.00	
10	27	3	0	742
	0.15	0.02	0.00	4.17
	3.64	0.40	0.00	
	32.14	15.79	0.00	
Total	84	19	2	17796
	0.47	0.11	0.01	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

Frequency / Percent / Row Pct / Col Pct	4	5	6	Total
11	2	1	0	742
	0.01	0.01	0.00	4.17
	0.27	0.13	0.00	
	2.38	5.26	0.00	
12	0	0	0	742
	0.00	0.00	0.00	4.17
	0.00	0.00	0.00	
	0.00	0.00	0.00	
Total	84	19	2	17796
	0.47	0.11	0.01	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

HOUR / Frequency / Percent / Row Pct / Col Pct	4	5	6	Total
13	1	0	0	741
	0.01	0.00	0.00	4.16
	0.13	0.00	0.00	
	1.19	0.00	0.00	
14	0	0	0	741
	0.00	0.00	0.00	4.16
	0.00	0.00	0.00	
	0.00	0.00	0.00	
Total	84	19	2	17796
	0.47	0.11	0.01	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

HOUR / Frequency / Percent / Row Pct / Col Pct	4	5	6	Total
15	0	0	0	741
	0.00	0.00	0.00	4.16
	0.00	0.00	0.00	
	0.00	0.00	0.00	
16	0	0	0	741
	0.00	0.00	0.00	4.16
	0.00	0.00	0.00	
	0.00	0.00	0.00	
Total	84	19	2	17796
	0.47	0.11	0.01	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

Frequency / Percent / Row Pct / Col Pct	4	5	6	Total
17	0	0	0	741
	0.00	0.00	0.00	4.16
	0.00	0.00	0.00	
	0.00	0.00	0.00	
18	0	0	0	741
	0.00	0.00	0.00	4.16
	0.00	0.00	0.00	
	0.00	0.00	0.00	
Total	84	19	2	17796
	0.47	0.11	0.01	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

Frequency / Percent / Row Pct / Col Pct	4	5	3	Total
19	0	0	0	741
	0.00	0.00	0.00	4.16
	0.00	0.00	0.00	
	0.00	0.00	0.00	
20	1	0	0	741
	0.01	0.00	0.00	4.16
	0.13	0.00	0.00	
	1.19	0.00	0.00	
Total	84	19	2	17796
	0.47	0.11	0.01	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

Frequency / Percent / Row Pct / Col Pct	4	5	6	Total
21	0	0	0	741
	0.00	0.00	0.00	4.16
	0.00	0.00	0.00	
	0.00	0.00	0.00	
22	1	0	0	741
	0.01	0.00	0.00	4.16
	0.13	0.00	0.00	
	1.19	0.00	0.00	
Total	84	19	2	17796
	0.47	0.11	0.01	100.00

TABLE OF HOUR BY NURSE

HOUR NURSE

Frequency / Percent / Row Pct / Col Pct	4	5	6	Total
23	2	0	0	741
	0.01	0.00	0.00	4.16
	0.27	0.00	0.00	
	2.38	0.00	0.00	
24	0	0	0	741
	0.00	0.00	0.00	4.16
	0.00	0.00	0.00	
	0.00	0.00	0.00	
Total	84	19	2	17796
	0.47	0.11	0.01	100.00

TABLE OF DAY BY NURSE

DAY NURSE

Frequency / Percent / Row Pct / Col Pct	0	1	2	3	Total
1	1544	517	302	83	2543
	8.68	2.91	1.70	0.47	14.29
	60.72	20.33	11.88	3.26	
	13.53	12.74	15.18	35.17	
2	1632	587	302	21	2544
	9.17	3.30	1.70	0.12	14.30
	64.15	23.07	11.87	0.83	
	14.30	14.47	15.18	8.90	
Total	11409	4057	1989	236	17796
	64.11	22.80	11.18	1.33	100.00

TABLE OF DAY BY NURSE

DAY NURSE

Frequency / Percent / Row Pct / Col Pct	0	1	2	3	Total
3	1602	601	306	33	2544
	9.00	3.38	1.72	0.19	14.30
	62.97	23.62	12.03	1.30	
	14.04	14.81	15.38	13.98	
4	1675	576	261	30	2544
	9.41	3.24	1.47	0.17	14.30
	65.84	22.64	10.26	1.18	
	14.68	14.20	13.12	12.71	
Total	11409	4057	1989	236	17796
	64.11	22.80	11.18	1.33	100.00

TABLE OF DAY BY NURSE

DAY NURSE

Frequency
Percent
Row Pct
Col Pct

DAY	0	1	2	3	Total
5	1693	590	242	19	2544
	9.51	3.32	1.36	0.11	14.30
	66.55	23.19	9.51	0.75	
	14.84	14.54	12.17	8.05	
6	1637	582	293	31	2544
	9.20	3.27	1.65	0.17	14.30
	64.35	22.88	11.52	1.22	
	14.35	14.35	14.73	13.14	
Total	11409	4057	1989	236	17796
	64.11	22.80	11.18	1.33	100.00

TABLE OF DAY BY NURSE

DAY NURSE

Frequency
Percent
Row Pct
Col Pct

DAY	0	1	2	3	Total
7	1626	604	283	19	2533
	9.14	3.39	1.59	0.11	14.23
	64.19	23.85	11.17	0.75	
	14.25	14.89	14.23	8.05	
Total	11409	4057	1989	236	17796
	64.11	22.80	11.18	1.33	100.00

TABLE OF DAY BY NURSE

DAY NURSE

Frequency / Percent / Row Pct / Col Pct	4	5	6	Total
1	76	19	2	2543
	0.43	0.11	0.01	14.29
	2.99	0.75	0.08	
	90.48	100.00	100.00	
2	2	0	0	2544
	0.01	0.00	0.00	14.30
	0.08	0.00	0.00	
	2.38	0.00	0.00	
Total	84	19	2	17796
	0.47	0.11	0.01	100.00

TABLE OF DAY BY NURSE

DAY NURSE

Frequency / Percent / Row Pct / Col Pct	4	5	6	Total
3	2	0	0	2544
	0.01	0.00	0.00	14.30
	0.08	0.00	0.00	
	2.38	0.00	0.00	
4	2	0	0	2544
	0.01	0.00	0.00	14.30
	0.08	0.00	0.00	
	2.38	0.00	0.00	
Total	84	19	2	17796
	0.47	0.11	0.01	100.00

TABLE OF DAY BY NURSE

DAY NURSE

Frequency / Percent / Row Pct / Col Pct	4	5	6	Total
5	0	0	0	2544
	0.00	0.00	0.00	14.30
	0.00	0.00	0.00	
	0.00	0.00	0.00	
6	1	0	0	2544
	0.01	0.00	0.00	14.30
	0.04	0.00	0.00	
	1.19	0.00	0.00	
Total	84	19	2	17796
	0.47	0.11	0.01	100.00

TABLE OF DAY BY NURSE

DAY NURSE

Frequency / Percent / Row Pct / Col Pct	4	5	6	Total
7	1	0	0	2533
	0.01	0.00	0.00	14.23
	0.04	0.00	0.00	
	1.19	0.00	0.00	
Total	84	19	2	17796
	0.47	0.11	0.01	100.00

Vita

Captain Annette M. Stephens was born November 4, 1966 in Fairbanks, Alaska. She graduated from Los Alamos High School in Los Alamos, New Mexico in 1984, and attended the U.S. Air Force Academy, graduating with a Bachelor of Science in Operations Research in 1988. Upon graduation, she was assigned to Headquarters Air Training Command at Randolph AFB. While at HQ ATC, she served as a resource analyst in the Command Analysis Division. She entered the School of Engineering, Air Force Institute of Technology, in August 1991.

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