ENGINEERING HEALTHCARE: SIX SIGMA AND COMPUTER SIMULATION IN AN EMERGENCY DEPARTMENT

THESIS

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This project used a combination of a computer based simulation tool, specifically the ProModel MedModel healthcare computer simulation tool, and a statistical-based continuous improvement methodology, Six Sigma, to model/analyze the daily operations of the Emergency Department (ED) at Central Texas Medical Center (CTMC) in San Marcos, Texas. The goal was to use these tools in an effort to decrease the variation in

the length of stay (LOS) for its patients. By decreasing the variation in LOS the resultant impact should be a reduction in the number of highly dissatisfied customers and a reduction in the mean LOS. In addition, there were two business goals – to increase the quality of care (especially in regards to reducing the number and sources of errors) and to decrease the amount of time to disposition a patient, especially in cases of admissions to the hospital.

Over the last seven months the Six Sigma project team used the Six Sigma DMAIC methodology (Define, Measure, Analyze, Improve, and Control) to identify several improvement projects that were targeted to address inefficient or ineffective ED processes. The team used this tool to systematically identify six major process inputs that needed improvement: the chart system for tracking patients within the ED process, the personnel that supported these processes, physician communication with patients and internal support personnel, diagnostic results (both laboratory and radiological processes), materials, and the equipment/supplies used to support the ED processes. The hospital is using the results of the Define, Measure, and Analyze phases to begin making improvements in their business processes. Some of the Improvement phase projects include the redesign of their materials supply rooms, redesigning the chart system used to track the progress of patients through the ED, redesigning the process for forwarding patients in the waiting room into the emergency room area, analyzing the root cause for variability in laboratory turn-around-times (TAT), writing new operating procedures for the transportation of patient samples to the laboratory, and using communication technology to improve the communication between personnel in the department.

Some of the early results show that the new Triage to ED bed process is dramatically reducing the variation in patient wait time for this portion of the entire process. This improvement is reducing the variation in patient lengths of stay. And, this decrease in wait time variability causes a concurrent, downward shift in the mean wait time. Thus, patients are spending much less time in waiting which has resulted in a decrease in the number of patients leaving the ED without being seen (LWBS). The project team found that the new, improved Triage to ED bed process decreased the number of LWBS patients from 32 to 16. Therefore, based on the average revenue generated from an ED patient of $505.67, the new process could generate an additional $97,089 per year! In addition, a root cause analysis of the variability in lab TATs pinpointed one, specific type of lab order as a culprit for the variability in TAT. Eliminating this cause of "special variation" in the process will reduce patient length of stay. Also, the redesign of the supply room and the use of communication technology are expected to make patient care more efficient. Once the implemented improvements are stable, the hard-won improvements will be controlled in the Control phase. Simple control charts, such as the x-bar and p-charts are to be used to keep the new processes under control.

Additionally, a computer simulation tool was used to explore several alternative process improvement scenarios. This tool is a great choice for engineers when they need to explore potential solutions that would be difficult to pilot in any "real" sense. The level of difficulty associated with a proposed change render solutions that may be too time intensive, cost prohibitive, or risky to pursue. The level of risk level may prevent feasible solutions from being tried at all. Conversely, experimentally changing a particular process only to find that the return was less than the investment would be worse. It would waste valuable time and resources. In this study an "as-is" model of the current ED system was built and analyzed; then it was compared to several "what-if" models to explore the effects of the following business scenarios: the addition of business hours for the ED's Minor Emergency Clinic (MEC), the installation of a PACS system to eliminate the transportation of x-ray film, the addition of a single Hematology Technician to draw and transport laboratory samples from the ED area to the lab, and new bedside registration and discharge processes. The computer simulations showed that the addition of a single Hematology Technician and the addition of the new bedside registration/discharge process did not significantly reduce patient LOS. However, computer simulations show that there were statistically significant reductions in the overall, mean patient LOS in the other two scenarios - the addition of MEC hours and PACS system installation scenarios. These two simulation models demonstrated a 3.3% and 3.8% reduction in the overall, mean patient LOS for each scenario respectively. The time, cost, difficulty, and risk levels are high for these types of proposed process improvements. Thus, computer simulation is an essential and valuable tool in assessing the effect of these business changes without actually changing the existing system.

CHAPTER 1

INTRODUCTION

The operation of a healthcare organization is not typically viewed from a business perspective. We frequently see reports on television, in newspapers, and in professional journals that paint the healthcare industry as being slow to embrace process improvement techniques in efforts to increase the quality and safety of healthcare. Up until the 1970's, the cost and quality drivers for healthcare were primarily determined by the medical profession or government licensing authorities (Business Roundtable, 2001). The business community was effectively left out of such decisions. Historically, processes within healthcare organizations have been fraught with inefficiency and errors. For the most part this is not because the individuals working in the industry were negligent, but because the culture of the industry emphasized "perfection" traits. Medical professionals were trained that mistakes were unacceptable. And, those that made mistakes were punished. Usually, corrective measures were focused on the individual that made that error and not on underlying causes of error. The fallacy of this culture is that latent design, organizational, and human factors are usually the real causes of error or inefficiency. The industry is beginning to realize that human error is inevitable. But, steps can be taken to redesign healthcare delivery systems to become more "mistake-proof". Also, the hospital industry is organizationally unique in that usually the doctors are not employees of the hospital. Doctors play a critical role in the continuous improvement of the organization, but it may be difficult to manage organizational improvements through indirect employees. This facet of the healthcare industry makes meaningful, lasting improvements more difficult to capture. The key is to approach improvement projects from a data driven perspective. Decisions in quality improvement projects should be data driven and not influenced by personalities. Once the culture changes to one that embraces errors and inefficiencies as opportunities to improve the system, only then can the industry approach the quality levels such as those seen in other industries (Leape, 2004). Routine, non-punishing investigation of medical errors and inefficiencies through the use of sound data collection tools will be the key to changing paradigms and improving healthcare systems. As one international quality advisor summed, "focusing on the processes, not the people, are the key to error-free performance (Harrington, 1991)."

Why Focus on the Healthcare Industry?

A 1999 congressionally chartered report, "To Err is Human", by the Institute of Medicine (IOM) found that anywhere from 44,000 to 98,000 die every year from preventable medical errors made in hospitals (Institute of Medicine, To Err is Human, 1999,). Alarmingly, these numbers do not include harm from mistakes made in outpatient settings (About Us, 2003). Contrast these numbers to the numbers of deaths due to other causes: motor vehicle accidents (43,458), breast cancer (42,292), and AIDS

(16,516). Thus, medical-error deaths rank as the eighth leading cause of death in America, even if one uses the lower estimate of 22,000 deaths per year (Gingrich, 2003). There was an expert in the industry that thought the IOM figures were too high – this person thought that the actual number of patients dying from medical mistakes was probably half the numbers reported in the study. But, even if the number of deaths was halved, to 22,000 deaths in the lowest estimate, this would be equivalent to a New York to Washington shuttle flight crashing every other day with no survivors (Gingrich, 2003)! A 1991 Harvard Medical Practice Study reported that 4 % of New York state hospital patients suffered iatrogenic injuries that prolonged their stay or resulted in measurable disability. Alarmingly, 14% of these injuries were fatal. Based on these incidence rates, and if extrapolated to the entire U.S. population, 180,000 people would die each year due to iatrogenic injury. This equates to approximately three jumbo jet crashes every 2 days (Leape, 1994). Obviously, the cost in terms of lives is substantial. Medical errors can be defined as the failure of a planned action to be completed as intended or the use of a wrong plan to achieve an aim (Institute of Medicine, To Err is Human, 1999). The most common types of errors are adverse drug reactions and improper transfusions, surgical injuries and wrong-site surgeries, suicides, restraint-related injuries and deaths, burns, falls, pressure ulcers, and mistaken patient identities. The highest error rates with serious consequences are most likely to occur in intensive care units, operating rooms, and emergency departments (Institute of Medicine, To Err is Human, 1999). And, there are many other hidden costs that are not as readily measurable – lost personal income, years of potential life lost, disability, longer rehabilitation, and increased insurance premiums – which contribute to the burden placed on society. These costs have been estimated to be between $17 billion and $29 billion per year in hospitals nationwide (Institute of Medicine, To Err is Human, 1999).

As the ranks of the unemployed/uninsured swell and the healthcare workforce becomes smaller in proportion to those seeking care the system swoons under the load. An ABC World News Tonight Report recently stated that there are now approximately 43.6 million uninsured and 46 million underinsured citizens in the United States (ABC World News Tonight, 2003). One out of ten children is uninsured and 59 percent of individuals are unsure that they can pay for health insurance in the future. Because of the skyrocketing costs of healthcare families now pay 49 percent more for healthcare than they did in the year 2000. A piece of this cost is attributed to a 13.9 percent increase in insurance premiums. So, Americans now spend 15 percent of our Gross Domestic Product (GDP) on healthcare, or about $1.5 trillion (Healy, 2003). In the 1950's the amount spent on healthcare was only 5 % of the GDP. It must be understood that some of this increase in spending is due to the increase in the availability of drugs and techniques that didn't exist in the 1950's. But, the root of today's problem is that most of us are not aware of the true cost of healthcare. There is no personal incentive to weigh price and value like we do when we are buying a personal computer (Healy, 2003). If we are insured, we may not care about the cost. The third party payer system disconnects the benefactor from the provider. The argument is that the current system is not market driven; therefore the cost for healthcare slowly spirals upward. This ultimately makes healthcare less affordable to some who need the care the most. So, for many Americans the emergency room has become the primary source of healthcare.

A visit to virtually any hospital emergency waiting room exposes the fact that our emergency departments are becoming increasingly crowded. The Centers for Disease Control and Prevention (CDC) reported in June 2003 that over the last decade emergency room trips increased approximately 20 percent - from 89.8 million visits in 1992 to 107.5 million in 2001 (Jones, 2003). To make matters worse the CDC also reported that the number of emergency rooms dropped by 15 percent. Another study completed by the American Hospital Association indicated that 62 percent of hospitals feel that they are operating at or over their capacity. The percentage jumps to 90 percent when considering only Level I Trauma Centers and larger 300 plus bed hospitals. And, the General Accounting Office reported that 66 percent of emergency departments diverted incoming ambulances in 2001 (Pexton, 2003). In addition, 1 out of every 10 hospitals reported being on diversion status more than 20 percent of the year (Jones, 2003). These numbers are alarming to the strategic managers of our nation's healthcare system. The overcrowding is due to many reasons – budget shortfalls, population explosion, a third-party-payer healthcare system that undermines the sense of responsibility an individual should possess regarding ones own health – all contribute to a problem that will require a multitude of solutions. The short-sighted response is to spend more money to add resources to the system. A study completed by the Metropolitan Chicago Healthcare Council determined it will need nine more 500-bed hospitals by the year 2020 (Dobbs, 2003). For many U.S. cities, the addition of resources will not be viable solution. Emergency rooms are likely to become more crowded. Couple this with the potentially devastating effects of terrorism attacks or an epidemic outbreak of diseases, like SARS, the healthcare system may meltdown.

So, the challenge will be for healthcare organizations to offer more services with fewer resources. The ability to apply sound, effective measurement skills will be the key to overcoming this challenge. A USA Today study of the 50 biggest U.S. cities found that most emergency response times are measured as the time it takes for an emergency crew to drive to the scene. When a baggage handler collapsed at the Los Angeles International Airport, it took 6 to 7 minutes for local fire and ambulance emergency response teams to arrive at the airport. It took a total of 30 minutes for the emergency personnel to reach the victim. Research done by the Mayo clinic showed that patients suffering from ventricular defibrillation - like the gentleman at the airport - have six minutes to live. The victim was "savable", but died due to the inflated emergency response time. The USA Today analysis reported that only 9 out of 50 of the largest U.S. cities track their emergency response times precisely enough to know whether or not their response teams reached the victim within six minutes. It is estimated that 1000 "savable" lives are lost each year due to inefficiencies in major U.S. cities emergency medical systems. Nationwide, about 250,000 people per year die from cardiac arrest. About 58,000 of these lives could be saved by a timely shock from a defibrillator (Davis, 2003). The first step towards eliminating unwarranted deaths and inefficiencies is to improve the way in which we measure healthcare processes. Measurements must be relevant (especially in regards to the customer's viewpoint), specific, standardized throughout the organization or industry, and well documented. Solid measurement skills allow professionals to become more proactive, adaptable, and responsive to changing business conditions. The idea is to possess a higher ability to successfully control or "steer" the organization towards its goals.

We also must consider the intangible costs - the nation may suffer as a whole from a loss in trust in the healthcare system. Currently, 54 percent of Americans are dissatisfied with the overall quality of healthcare (Langer, 2003). Our citizens pay with physical or psychological discomfort. Health professionals pay with loss of morale and job dissatisfaction (Institute of Medicine, To Err is Human, 1999). The trust issue is highly scrutinized. It is a regular high-interest topic at the local, state, and national level. As a result the healthcare industry is now at a major crossroads in their history - they must act quickly to regain consumer and governmental confidence. From a product delivery standpoint, there will be increasing pressure for the healthcare industry to provide hard evidence that they can safely and efficiently deliver a quality product. They will also need to build adaptable systems that are able to respond to any customer request. Finally, the industry will need to be able to continuously improve their business processes.

The Healthcare Business Model

Basically, a hospital is a business just like any manufacturer or service provider. And these businesses require inputs – raw materials, machinery, inventory, professional services, support personnel, brick and mortar, energy sources, and patients. A manufacturer adds value to the inputs to create a marketable, physical entity – a product. In contrast, service organizations or hospitals use the inputs to add value to a different kind of entity. In the healthcare industry the entity is the patient. The patient as the entity is an important aspect of this particular industry – arguably more important than the product produced by manufacturers - as one consultant stated "We're talking about people's lives and their health (ASQ, 2003)." Somehow they must add value to the entity in order to make a profit. They add value by providing a service in the form of inspections and alterations that yield healthier people. In other words, they inspect people to insure that they are well and they also render therapeutic measures to people to fix what is wrong. Healthier people are the output. Healthier people in turn are more productive, and are able to contribute to the social and economic well being of the community. Thus, the healthcare organization as a business produces a valuable product. However, many forget that this is a tough product to sell, much tougher than selling a manufactured product such as a toaster. We must remember that the entity that we are adding value to is already "damaged" or potentially "flawed" to begin with. The difficulty lies in selling a product that can significantly overcome this low, initial satisfaction level. Initially, the healthcare customer is probably not too satisfied, so a healthcare service provider must work hard to overcome this initial level of dissatisfaction. If successful, the healthcare organization may capture more business.

In addition, it is easy to overlook the impact of doing business upon the healthiness of your internal customers. Employees need the correct tools and processes to efficiently add value to the external customer. Without a satisfied workforce, business goals may suffer due to reduced productivity.

Historical Perspective on Quality Movements

Unfortunately, the healthcare industry is late in recognizing the benefits of some of the operational sciences that were embraced by the manufacturing industries in the early 1970s through the 1980s. In response to global competition, many U.S. manufacturing companies realized that they could no longer "push" products onto the open market. And to make matters worse, some of the products they were pushing were of substandard quality and of poor design. Overseas competitors were able to grow their businesses by providing quality products that accurately met customer requirements. As American companies' market shares shriveled they realized they needed to reinvent how their companies viewed the customer, their internal operations, and the global marketplace in general. For some it was a matter of survival. Paradigms needed to change and change quickly. Many scrambled to study the business techniques and organizational culture of overseas competitors, especially Japanese techniques. The Japanese companies were leveraging the techniques of "Total Quality Management", "Process Engineering", "Theory Z Management", "Kaizen", "Lean Manufacturing", and many others in order to take the world market by storm. Products made in Japan became synonymous with the word "quality". A case in point – engineers and managers from a Buick Division of General Motors visited one of their Tokyo dealerships. When they arrived they noticed that the dealership appeared to be a large repair facility. When they asked the dealer how he had managed to build such a large service business, the dealer replied that the operation was not really a repair facility; they were simply disassembling the newly imported Buicks and rebuilding them to Japanese standards. He explained that although the Japanese consumer was drawn to the American automobile, they would never accept the low quality with which they were put together (Ouchi,1981, pg. 3). American businesses started to study the Japanese way of doing business. Over the next three decades a cascade of quality based improvement programs were initiated at companies throughout the world. The quality gap was beginning to be reduced, but even in 1990 American manufacturers were struggling to compete. A major American auto corporation ran an ad in the June 11th, 1990 issue of USA Today that stated their competition was 300% better than they were in 1980, but by 1990 their competition was only 25% better (Harrington, 1991)! It should suffice to say that this sort of advertising did not win customers. Obviously, improving business processes remained a high priority in the boardrooms. The goal of many American companies was to substantially change the way companies do business. The healthcare industry was left behind. However, governmental and economic forces provided the impetus for change.

Governmental, Private, and Professional Forces on the Healthcare Industry

In 1974, the passing of the Employee Retirement Income Security Act (ERISA) gave self-insured businesses the opportunity to take control over medical benefits (Business Round Table, 1997). The act played a key role in making healthcare coverage available to millions of American families. The law enabled businesses to tailor their own healthcare plans and afforded them an easier administrative task of operating under a uniform federal regulation instead of sundry state laws (Statement, 1997). Then, in the 1980's the cost of healthcare ballooned. By 1982, employer expenses for health benefits were equal to 50% of pre-tax profits (Statement, 1997). Today, business expenditures for health services account for more than 8% of total employee compensation, versus just 2% in 1970 (Statement, 1997). Many large companies were suddenly faced with liabilities that could potentially force them out of business or into restructuring scenarios. These companies took action to take a leadership role in controlling healthcare costs. One of the earliest business responses was the creation of "managed care" healthcare. Companies were able to leverage their healthcare buying power by creating health maintenance organizations (HMOs). By 1997, almost three quarters of employees at major companies were members of some type of managed care plan (Statement, 1997). That figure is certainly higher now. The leadership role was advanced by actions taken by the Business Roundtable – an association of more than 200 CEOs of leading U.S. corporations. These CEOs and their companies represented about 10 million Americans and approximately 25 million total family members. Their decade of experience in the healthcare arena, and a couple of decades of experience in quality control techniques, prompted them to found the Leapfrog Group.

The Leapfrog Group was launched in November 2000. The group is comprised of a large consortium of Fortune 500 companies and other large healthcare purchasers, both public and private, whose goal is to foster breakthrough improvements in the safety, quality, and affordability of healthcare for Americans (Factsheet, 2003). The mission of the Leapfrog Group is to make the American pubic aware of the advances in patient safety. Suzanne Delbanco, executive director of the Leapfrog group stated, "Consumers deserve to know what steps hospitals are taking to keep them safe (Press release, 2002)." And, the mission is to specify a set of purchasing principles designed to promote safety advances as well as customer value. Their mission was developed from four main ideas:

1. The American healthcare system remains far below obtainable levels of basic safety and overall customer value.
2. The healthcare industry would improve more rapidly if purchasing processes better recognized and rewarded superior safety and overall value.

3. Voluntary adherence to purchasing principles by a critical mass of America's largest employers would provide the "jump-start" to encourage other purchasers to practice the same purchasing principles.
4. The purchasing principles should not only be supportive of overall value goals, but also focus on those specific innovations offering "great leaps" in basic patient safety. This would in turn maximize media coverage and consumer support which would lead to the adoption of these innovations by other healthcare purchasers (Factsheet, 2003).

Based on these principles and the mission statement the Leapfrog member committees have collectively agreed to adhere to the following four purchasing principles:

1. Educate and inform enrollees about patient safety and the importance of comparing healthcare provider performance, with the initial emphasis on the Leapfrog safety measures.
2. Recognizing and rewarding healthcare providers for major advances in protecting patients from preventable medical errors.
3. Holding health plans accountable for implementing the Leapfrog purchasing principles.
4. Building the support of brokers and consultants to utilize and advocate the Leapfrog principles benefit all their clients (Factsheet, 2003).

Item #1 above is an important principle in that it specifically addresses the importance of being able to measure healthcare performance. This is crux of the issue since without the ability to measure we can not compare one provider against another. Once the purchasers of healthcare are armed with meaningful data regarding the performance of healthcare organizations, they can then make intelligent consumer decisions. Consumer demand, or the lack of their demand, can spark significant improvements in the industry.

The Leapfrog Group has refined three hospital safety measures that are the basis for comparing healthcare organizations and are used for hospital recognition and reward:

1. Computer Physician Order Entry (CPOE) - Physicians enter medication orders via computer. The medication orders are then linked to prescription error prevention software. This has been shown to reduce serious prescription errors in hospitals by more than 50%.
2. Evidence-Based Hospital Referral – Hospitals that offer certain complex medical procedures are scientifically measured. Survival odds scores are computed for each procedure a particular hospital offers. Research indicates that a patient's risk of dying could be reduced by more than 30%.
3. Intensive Care Unit (ICU) Physician Staffing (IPS) – Staffing ICUs with physicians who have credentials in critical care medicine has been shown to reduce the risk of patients dying in the ICU by more than 10% (Factsheet, 2003).

The Leapfrog Group's efforts have led to astounding results. Their research shows that if urban and suburban hospitals implement the three patient safety practices above, nearly 60,000 lives could be saved and more than half a million serious medication errors could be prevented each year. In addition, approximately $9.7 billion dollars could be saved annually (Press release, 2002). In November of 2002, only 2 years after its inception, the Leapfrog Group reported that 70% of American healthcare consumers now had vital patient safety data for one or more hospitals in their area (survey info is available to consumers at www.leapfroggroup.org).

The Leapfrog Group member companies provide us with an insight into specific actions taken in order to "force" improvements into the healthcare industry from the consumer side. One executive from Allied Signal (now merged with Honeywell) said "We think [healthcare] finance is going to be driven by taking poor quality out of the process. In the final analysis, that will be the value equation: doing it right the first time." Allied Signal uses its expertise in Six Sigma tools to actively manage its business relationships with healthcare providers. The goal is to have near zero defects. They negotiated a guarantee with a health plan carrier that focuses on such simple customer satisfiers such as the time it takes the carrier employees to answer the phone (Business Round Table, 1997). Some companies strategically pool their health plan requirements together in order to maximize the chances for improved quality. Baxter, GTE, and AT&T collaborate on "best practices" and other quality improvement measures. These companies and others have dropped healthcare plans that do not meet their strict quality standards (Business Round Table, 1997). United Technologies told its insurance carrier "We have adopted *kaizen* [continuous improvement through incremental changes] on the factory floor, and we want you to reexamine your key processes, for example, referrals, in a similar manner (Business Round Table, 1997)." Clearly, this is a great example of the way in which manufacturers are applying Japanese manufacturing process improvement tools to the healthcare problem. Tenneco contracts with top-performing hospitals for certain procedures – cancer treatment, neurosurgery, reconstructive surgery, and treatment of children's diseases – and it flies its employees to those providers in order to ensure excellent healthcare service (Business Round Table, 1997).

Some notable organizations have also teamed up with the Leapfrog Group. The Robert Wood Johnson Health Network, a partnership of seven New Jersey hospitals, invested $40 million dollars to implement Leapfrog Safety practices by 2005. Interestingly, The Robert Wood Johnson Foundation conducted a national survey of quality representatives and stated that there is no Toyota in healthcare – in other words there is not a single healthcare organization that has developed a comprehensive approach to world-class quality similar to Toyota's approach in the manufacturing arena (Merry, 2003). Also, Blue Shield of California announced that it would include the Leapfrog practices in its hospital "network choice" tiered program to determine hospital quality efforts (Press release, 2002). In May of 2001 the Leapfrog Group won the prestigious Ellwood Award for outstanding efforts to foster consumer-focused accountability in healthcare. The Ellwood Award is named after Dr. Paul Ellwood, M.D., who brought healthcare, public policy, and business leaders together for nearly three decades in efforts to share ideas and strategies for building an accountable, consumer-focused American healthcare system (Business Roundtable press release, 2001). This award and the important organizational additions highlight the evidence that the Leapfrog Group has established momentum and that the "spillover effect" will have a significant, long-term impact on the quality of healthcare in the United States.

The Business Roundtable's Leapfrog Group is certainly not the only organization that is focusing on improving the healthcare industry. The 1999 report from the Institute of Medicine laid out a comprehensive strategy by which government, healthcare providers, industry, and consumers could reduce medical errors. One of the main conclusions of this report was that a majority of medical errors do not result from individual recklessness or conscious actions of a single group (Institute of Medicine, To Err is Human, 1999). In other words there is not a "bad-apple" problem. Instead, they stated that most errors are the result of faulty systems, processes, and conditions that lead people to make mistakes or fail to prevent them (Institute of Medicine, To Err is Human, 1999). Thus, simply "fool-proofing" the opportunity for making a mistake could eliminate mistakes. For example, the healthcare industry would be best served in this regard by implementing the Japanese poka-yoke manufacturing technique, which would virtually eliminate chances of error. Ultimately, the Institute of Medicine report resulted in a $50 million appropriation to the Agency for Healthcare Research and Quality (AHRQ) to support efforts in reducing the number of medical errors (Institute of Medicine, To Err is Human, 1999). The Robert Wood Johnson Foundation also has their own initiative, called Urgent Matters, which is a $4.6 million initiative aimed at helping hospitals eliminate emergency department crowding and helping communities understand the challenges associated with the use of emergency rooms as a healthcare safety net. Under the initiative up to ten hospitals will receive $100,000 grants to implement and develop best practices to relieve emergency room crowding. Four of the ten hospitals will receive up to $250,000 in funding and will receive specific innovations or improvements to lessen crowding (urgentmatters.org, 2003).

Professional groups within the industry have also been actively pursuing quality improvements in healthcare. The Council on Graduate Medical Education (COGME) and the National Advisory Council on Nurse Education and Practice (NACNEP) held a joint meeting to discuss the following issues: the effect of nurse/physician relationships on patient safety, the impact of nurse/physician collaboration on systems designed to protect patient safety, and educational programs to ensure interdisciplinary collaboration to ensure patient safety (Institute of Medicine, To Err is Human, 1999).

The Joint Commission on Accreditation of Healthcare Organizations (JCAHO) is a governmental organization that offers a certification program for healthcare businesses. A hospital or healthcare provider attaining JCAHO certification has demonstrated that it operates its business at a satisfactory level of quality and safety. JCAHO is becoming increasingly sensitive to the need for data driven performance measurements. It currently requires organizations to engage in at least one quality improvement program. And, beginning in January 2004 an additional set of core performance measurements will be required from accredited hospitals. Hospitals will need to measure and report two to three sets of core measures from a set of four possible measurements: acute myocardial infarction, heart failure, community acquired pneumonia, and pregnancy conditions (ASQ2, 2003). The trend for JCAHO is to accredit those hospitals that have a proven ability to define, measure, analyze, improve, and control their processes. Likewise, a healthcare organization can obtain certification from a private organization such as the ISO organization. Both ISO and JCAHO are similar in that they help consumers make decisions regarding where they want to purchase their healthcare needs.

Other governmental forces should be considered in the context of improving healthcare. Some laws are designed to insure quality in specific segments of the healthcare industry. For example, the Emergency Medical Transfer and Active Labor Act (EMTALA) of 1986 applied to any hospital that participated in Medicare transactions and provided emergency services. Under the law any person that visits an emergency department of a hospital for treatment must be administered a “medical screening examination." And, if the diagnosis is categorized as an emergency medical condition, the hospital has to provide treatment to stabilize the patient. The hospital can also transfer the patient to another organization if the benefits of the transfer outweigh the risks associated with delayed care. The law was beneficial in that it helped provide the uninsured with critical healthcare needs. In 1998, 16.3 million emergency room visits were by uninsured patients (Bourgeois, 2003). The difficulty with the rule was that it applied to all hospital departments, even those that were not physically located at the main hospital location. In addition, hospitals participating in Medicare had to keep an appropriate number of staff physicians and specialists on call to treat emergency patients. Hospitals and doctors have lobbied for changes to the ETMALA law as emergency rooms were becoming more crowded. People began to use emergency rooms as a source of "free" healthcare. Interestingly, the "free" healthcare loophole allows certain individuals to abuse the system. For example, adults frequently seek medical services in a Boston children's hospital emergency room (CHEDs). The hospital is required to treat these adults under the ETMALA provision. A study examined 501,033 patient visits to CHEDs from 1992 through 2002. Chi-Square statistical tests showed a significant increase ($p < 0.001$ for both results) in the total number of adult (22 years or older) visits and the number of new, first-time adult visits after the implementation of ETMALA in that hospital (Bourgeois, 2003). In addition, court cases resulting in suits and fines for violators of the law has served to increase the layers of regulations added onto the law. Hospitals were afraid to move people out of fear of being sued. Those that lobbied for modification to ETMALA were successful. The rules for ETMALA changed on November 10, 2003 (Pear, 2003).

The Bush administration is easing the ETMALA rules that dictate how emergency care is provided by hospitals. There is a relaxation of the physician and/or specialist "on-call" rules. ETMALA will no longer apply to any individual that is admitted as an inpatient. And, the new rules clarify that the law does not apply to rural health clinics, nursing homes, doctor's offices, or other "non-hospital entities," Thus, a hospital with satellite departments, detached from the main campus, that do not offer emergency care are exempt from ETMALA rules. Patients still reserve the right to sue, but in many cases, hospitals will be more successful in defending their particular positions (Pear, 2003). ETMALA and the impending new law highlight some of the issues surrounding the "overcrowding" problem unique to healthcare emergency departments.

Quantitative Measurement within the Healthcare Industry

Consumers are becoming increasingly aware that the best healthcare suppliers will have an established record of safety, cost control, high satisfaction levels and perhaps more importantly, a culture that embraces continuous quality improvement. In June 2002, health profession leaders and experts attending a Health Professions Education Summit developed strategies for health profession education. Interestingly, their report said that doctors, nurses, pharmacists, and other professionals are not being adequately prepared to provide the highest quality and safest medical care possible. And, that there was inadequate assessment of their ongoing proficiency. Their advice was that educational, licensing, certification, and accreditation organizations should ensure that healthcare professionals are proficient in five core areas:

1. Delivering patient centered care

2. Working as part of interdisciplinary teams
3. Practicing evidence-based medicine
4. Focusing on quality improvement
5. Using information technology (Institute of Medicine, 2003).

Measurement skills are critical to tackling the first four core areas. Healthcare professionals need to be able to measure how well they are delivering patient care and how well they work together as a team. They need to measure medical outcomes and make comparisons to be able to provide evidence of safe, quality medicine. And, they need quantitative measurement skills in order to continuously improve their office, work environment, and profession.

Quantitative Tools – Six Sigma

An important process improvement movement is the "Six Sigma" culture. Six Sigma is a set of statistical and management tools aimed at process improvements. The term "sigma" refers to a measure of variability of data and is denoted by the lower case Greek letter sigma (σ). The measure of data variability is called standard deviation. Thus, one standard deviation is a measure of a certain distance from the mean (average) for a data set. And, there are certain mathematical facts that hold true for data that are distributed normally around the mean – 99.74% of the data points in the data set fall within plus or minus 3 standard deviations from the mean. If we consider data that fall within plus or minus 6 standard deviations from the mean, and allow for a worst case scenario of a 1.5 standard deviation shift in the mean, only 3.4 data points out of 1,000,000 will fall outside the 6 sigma range of data. This 6 sigma measure of variability has been used to characterize defect rates or process performance in the manufacturing industry. Thus, in a manufacturing context 99.9997% of the data, or opportunities, are of acceptable quality. Statistically, any process that produces 3.4 defects or less per one million opportunities performs at a six sigma level.

The Six Sigma movement was designed to help an organization focus on customer needs from the inside out. First introduced at Motorola by Mike Harry and the late Bill Smith in 1986 the Six Sigma tool has grown to the point where approximately 15% of the nations Fortune 1000 companies are using it in a significant way (Jones, 2002). It should be noted that many of these companies are members of the Leapfrog Group. Companies such as Honeywell (including the former Allied Signal), Raytheon, and GE have made it a significant part of their organization's culture. These companies believe that Six Sigma is an important strategic tool – a tool that transforms the way they do business. The companies that successfully implement Six Sigma align corporate goals with the company's people and processes. Six Sigma transforms people at all levels within the organization – how their tactical goals are determined, how their productivity and job performance are measured, the tasks that make up their jobs, and how they interact with peers and customers (Smith & Blakeslee, 2002, pg. 40).

Unfortunately, many non-Six Sigma improvement programs end up being categorized as mere "schemes". Programs that lack the support of the organizations top leaders characterize these schemes. Some of the early Total Quality Management (TQM) programs suffered from the lack of executive leadership. Subsequently, many TQM projects were misaligned with business strategic goals. And, eventually many projects slowly lose their vitality and die from a lack of support, employee involvement, and funding.

Some of the Six Sigma techniques have emerged as truly useful strategic tools. These are tools that dramatically impact the way organizations view themselves and their customers. Six Sigma is designed to be a lasting tool – one that is continuously used to improve the organization. According to Joseph A. De Feo, CEO and President of the Juran Institute, the healthcare industry needs to look at Six Sigma for three reasons. "There is a significant need to improve clinical outcomes, to reduce the costs of healthcare, and to improve patient satisfaction (ASQ, 2003)."

At the root of Six Sigma efforts is the ability to measure the performance or capability of a process. Good data are the key to meaningful data analysis. The problem for the U.S. healthcare industry is that in many situations there is not a standardized method for measuring process performance. For many situations, the process variable that is measured is misleading – and the data may hide or mislead outsiders into believing that the process is not broken.

Six Sigma within the Healthcare Industry

The healthcare industry was historically built around a preindustrial revolution craft model – train the caregivers, give them a certain amount of resources, and then let them alone as they provide for their patients' care. Thus, patient care was administered via specialized silos of expertise, and no one was focused on patient-centered approaches. The specialized care model worked in the past, but in the complex, technologically advanced 20th century hospital, there is a need for comprehensive solutions to the physical and informational needs of the patient. The quality capability of the industry in the preindustrial age may have been at best 2 – 4 sigma. In the postindustrial age, the demand will be for Six Sigma quality capabilities (Merry, 2003).

An inspection of the emergency response situation in Houston, Texas provides an excellent example of a team taking the necessary efforts to truly understand their problem and then taking appropriate actions to improve the process. Their original sudden cardiac arrest survival rate went from near zero in 1983 to about 20% in 1988 after it improved their data measurement program and instituted meaningful process improvements. Attaining a twenty-percent survival rate is an amazing improvement considering that the nation's emergency medical systems typically save an estimated 6 to 10% of cardiac arrest victims. This is just one example of an emergency situation, and one small portion of the entire healthcare services spectrum, but it should be clearly evident that a tool like Six Sigma can revolutionize the industry (Davis, 2003).

Computer Simulation within the Healthcare Industry

Another emerging quality improvement tool is the use of computer simulation software to model business processes. Simulation modeling tools are used to inexpensively imitate complex working environments. There are many examples of physical simulation models: a wind tunnel to simulate flight conditions, flight simulators to train pilots, or underwater training to simulate the effects of zero gravity for astronauts. Models can also be characterized as symbolic (or schematic) and analytical. A symbolic model may take the form of a flow or organizational chart. An analytical model is one represented by expressions or equations that describe relationships within a system and can yield mathematical solutions for a given set of inputs. Recently, computing technologies have enabled the electronic simulation of real-world systems. An engineer does not have to build an analogue model, rather he or she can build a computerized, electronic model to simulate a situation. More importantly the engineer can modify this model quickly, easily, and cheaply in order to assess the feasibility of a different process or working environment. The benefit of this tool to healthcare professionals is that it may allow one to cheaply model and analyze systems within their organization. For example, it would be relatively difficult and expensive to make staffing, scheduling, or facility design changes to an emergency department compared to using a computerized simulation program. And, making real-world changes to a system doesn't guarantee that those changes will produce the desired results. It is possible that the changes will prove to be detrimental to the operation. Simulation modeling separates the analytical decision making process from the actual workplace setting. Therefore, it reduces the costs and risks in making critical, strategic decisions. An additional advantage is that simulating new, experimental models is done in an objective manner. Since the changes are not real, they are simulated in a computer; this effectively eliminates many threats to the internal validity of the experimental models. The threats of researcher bias, history, and the effects of testing such as the Hawthorne effect are eliminated.

Central Texas Medical Center - San Marcos, Texas

The directors and staff of the Central Texas Medical Center are visionary leaders interested in similar continuous improvement efforts. They recently completed JCAHO certification – their hospital scored a 98 out of 100 points, and their home health and hospice care section scored a 99 out of 100 points. They are also embracing technological improvements by investing millions of dollars in information technologies. Their goal is to transition to an information system that uses all electronic medical records and paperless transactions within the next two years. Also, the hospital collaborates with local schools and Texas State University in order to promote higher education and continuous improvements in the healthcare field. Over 100 auxilians and nearly 100 Texas State University interns volunteer their services to the hospital (Central Texas Medical Center, 2003). In alignment with these strategic goals, their leaders have agreed to allow a study of their emergency room operations.

The focal point for the application of Six Sigma and Simulation quality improvement tools in this study will be upon the business processes of a hospital emergency department. It has become increasing important to structure emergency departments that are effective, efficient, and flexible to customers' sundry health needs and expectations. CTMC in a 113-bed acute-care general hospital and is one of the 37 hospitals in ten states operated by the Adventist Health System (AHS). The Adventist Health System was established in 1973 and is the largest not-for-profit, Protestant healthcare organization in the United States. Today, their hospitals, long-term care, and home healthcare divisions serve more than 3 million people annually. Their mission is to provide physical, mental, and spiritual services in efforts to build healthier communities. They are committed to working with the communities in which they serve to reduce the incidence of disease, morbidity, mortality, accidents, and injuries (About AHS, 2003). In 2001, the CTMC emergency room experienced about 30,700 patients – or about 84 per day. The emergency room visit rate quoted in August 2003 was 2750 patients per month – or about 92 per day. This represents about a 9.5% increase in the emergency department workload within 2 years. About fifty percent of these patients end up as inpatients and half of these are cardiac patients. Historically, their observations are that emergency room departments are overcrowded, not only in San Marcos, Texas; but throughout the United States. Their perception was that the overcrowding was partially responsible for customer dissatisfaction levels. And, they believed that their internal service processes were likely contributors to customer dissatisfaction. So, they enlisted the help of the Gallup organization to measure consumer sentiment. What they found was that they were scoring in the 4th percentile in terms of patient satisfaction. This was alarming as this meant that 96% of their "competitors" were scoring higher than themselves. They continued to measure patient satisfaction and they have realized satisfaction increases over the last 4 years. In their fourth quarter of measurement they had improved to 30th percentile. By the end of their business quarter two they had improved to the 60th percentile. Their current goal is to reach the 80th percentile in customer satisfaction. Among many subcategories of sources for dissatisfaction on the Gallup poll CTMC's patients have identified ED "waiting time" as the highest dissatisfier. Thus, the area in which CTMC would like this study to focus is the amount of time emergency room patients are idle. The objective is to study the emergency department process and identify where and why patients are waiting for service, and ultimately to decrease patient length of stay (LOS).

Statement of the Problem

This project will employ the use of Simulation and Six Sigma techniques to analyze the daily operations of the Emergency Department facilities of the Central Texas

Medical Center in San Marcos, Texas. Historically, the hospital has enlisted an external organization to measure emergency room customer satisfaction levels. The resulting data have pointed to the need for a thorough, focused, continuous improvement effort in this area. In order to successfully service the growing healthcare needs of the community, the hospital is exploring the use of quantitative methods to increase patient satisfaction levels and decrease operating costs.

Research Questions

Can Six Sigma and Simulation statistical process control techniques be combined successfully to improve a service-based healthcare related process?

Can these tools successfully be used to define measure, analyze, improve, and control cycle times - or waiting times - within an emergency room department?

Can the cost of poor quality be measured within an emergency room department?

Can the capacity and/or productivity of an emergency room department be improved?

Is there a significant difference in the satisfaction levels of emergency room patients as measured before and after implementation of process improvements?

Significance of the Study

The literature regarding the use of either Six Sigma or Simulation quality improvement techniques within the healthcare industry is rare in comparison to their use in manufacturing settings. This study is planned to be differentiated from other healthcare quality studies via the application of both of these statistically based quality improvement tools: Six Sigma and Simulation. Specifically, this study will use MedModel, a simulation program developed by Pro Model Corporation, as the simulation software tool.

Limitations of the Study

Available resources, time, and technologies limit the applicability of this study. Some of the specific limitations are as follows:

The simulation and Six Sigma applications are limited to the Emergency Department facilities at Central Texas Medical Center in San Marcos, Texas. Thus, the results and conclusions of this study may not be applicable to similar environments. The emergency department is a fairly complex operation with varying inputs. Different operational procedures and organizational policies, which applied to both the patients and staff, were subject to change during the course of the study, potentially without the knowledge of the researchers.

The data obtained during the course of the study were tabulated from three different sources: historical records, direct observations, and interviews. The accuracy and precision of the data could vary depending on the individual directly involved in data collection, transformation, and analysis. In addition, the data gained from interviews are highly subjective. In a few cases, mean values for variables were calculated from the results of multiple interviews. When possible the mean values calculated from interviews were compared to other historical records to verify data validity.

The inputs for the Six Sigma tools depend heavily upon the perceptions of the project team members. Although the tools use a scoring system designed to target appropriate areas of opportunity, the inputs and use of the tools have some degree of subjectivity.

The design and scope of the computer simulations are limited to the capabilities of the ProModel MedModel version 6.0 software and the experience level of the user. The level of complexity in a service environment is difficult to simulate. Any simulation requires a tradeoff between complexity and simplicity. Many of the ED processes in the models were simulated in a serial manner instead of a parallel manner. The level of difficulty involved in simulating multiple processes, with some of these processes occurring in parallel with one another, would have required extensive data collection and programming time. In addition, to maintain simplicity some of the ancillary processes were simulated in a global manner instead of attempting to simulate the minute details of the process. For example, the overall distribution of lab sample service times were used in the model instead of adding unnecessary complexity to the model by attempting to simulate the service time for each type of lab sample within multiple sub departments of the lab department.

Glossary of Terms

5S - a key aspect of the Japanese River Flow philosophy of Production. It is comprised of 5 words that are the basis for process improvement programs: Seiri (say-ree) Sort/Discard, Seiton (say-ton) Arrange/Order, Seiso (say-zo) Clean/Inspect, Seiketsu (say-ket-soo) Standardize/Improve, Shitsuke (shit-soo-kay) Believe/Discipline.

6 Ms – the six Ms are as follows: Man, Machine, Mother Nature, Materials, Methods, and Measurements. These categories are sometimes used to categorize ideas from any of the brainstorming techniques.

Affinity diagram – a graphical, quality management tool used to organize ideas surrounding a particular management issue. Brainstorming sessions are used to develop the diagram (Kantutis et al., 1991).

Binomial distribution – a distribution of data in which the outcome for each measurement can only be one of two possible values.

Brainstorming – a free flow, unstructured, exchanging of ideas between key stakeholders for a particular problem. The goal of a brainstorming is to generate as many ideas as possible without regard as to whether the ideas are right or wrong. The generation of the ideas can be done silently. Clarification and judgment of ideas is usually deferred to another time. This tool is usually followed up by a discussion/clarification of the ideas, voting, and a Pareto Analysis. (Enterprise Concepts and Fundamentals CIRM workbook, APICS, 1997).

Cause and Effect Diagram/Matrix – a pictorial chart used to represent causes that contribute or lead to a final effect. Also called an Ishikawa diagram or Fishbone chart (Enterprise Concepts and Fundamentals CIRM workbook, APICS, 1997). Useful in group settings and for situations in which little quantitative data is available for analysis. An added benefit is that it can help bring about a more thorough exploration of the issues behind a problem (Simon, 2003).

Comparison chart - A graphical summary of an organizations process performance compared to a standardized, expected performance level. It is a statistical based chart. It differs from a control chart in that the norm for a process is obtained based on multiple healthcare organizations performance data, not its own historical data (Lee & McGreevey, 2002).

Control chart – A graphical, statistical based chart that provides a running log of a process or attribute over time. Its benefit is being able to distinguish between common causes and special causes of variation. More sensitive than a run chart in identifying special causes (Lee & McGreevey, 2002).

DMAIC – the GE developed tenet of their Six Sigma methodology that consists of five process improvement stages: Define the problem, Measure the gap, Analyze to find root causes, Improve the process through identity, implementing, and testing; and Control to hold the achieved gains (Benedetto, 2003) (ASQ, 2003).

Flowchart – A quality tool that is a graphic symbolic representation of the work performed in a process. The information in the chart usually shows start/stop, operation, transportation, inspection, storage, delay, and combined activity points for each stage within the process. It can also include information regarding quantities, distances, type of work done, and equipment used (Blackstone, et al., 1995).

Grand mean - the overall process mean calculated by dividing the sum of the relevant interval means by the total number of intervals. Sometimes referred to as "double x-bar" (Lee & McGreevey, 2002).

ICU – Intensive Care Unit.

Jidoka – autonomation, or an automatic control of defects. An in-process quality control mechanism (Enterprise Concepts and Fundamentals CIRM workbook, APICS, 1997).

Kaizen - The Japanese term for improvement; continuous improvement activities that involves everyone in the organization (Blackstone, et al., 1995). In Japanese "kai" means change, and "zen" means good.

Kanban – A Japanese term meaning card, billboard, or sign. A technique of Just-In-Time production that uses standard containers/locations and "pull card" attached to each container used by the operator to signal the "pull" of materials or subassemblies (Blackstone, et al., 1995).

Kano Analysis – a quality measurement tool used to prioritize customer requirements based on their impact to customer satisfaction. Different groups of customers may have different requirements, so the analysis can be used to identify customer segments and their needs (Carder, 2003).

KPIs - Key Process Indicator.

KQC – Key Quality Characteristic. Of several customer identified quality characteristics, it is the most important characteristic that the team identifies as a focal point for their efforts (Carey & Lloyd, 1995).

Lean Manufacturing - a manufacturing/production philosophy that emphasizes the minimization of the amount of all resources used in the organization. The goal is to shorten the lead-time between customer order to the shipment of a product through the elimination of waste (Alukal, 2003). It involves identifying and eliminating non-value added activities in design, production, supply-chain management, internal processes, and business to customer interactions (Blackstone, et al., 1995).

MedModel - software manufactured by ProModel specifically designed for simulating processes in a healthcare environment.

Murphy's Analysis – a brainstorming technique.

NICU – Neonatal Intensive Care Unit (Press release, 2002).

p-chart - a type of control chart. The proportion measure chart. The data is count data (Lee & McGreevey, 2002).

p-value – the probability making a Type I error. Also, described as the probability of obtaining the same or more extreme data than the observed when the Null Hypothesis is true.

Pareto Analysis - The process of ranking opportunities for improvement for the purpose of deciding which opportunity to pursue first (Carey & Lloyd, 1995). It consists of 3 basic steps: List all possible causes of a problem, collect data to determine the extent to which cause contributes to the problem, and rank the causes of the problem (Enterprise Concepts and Fundamentals CIRM workbook, APICS, 1997).

Poka-yoke – mistake-proofing. An in-process quality control mechanism (Enterprise Concepts and Fundamentals CIRM workbook, APICS, 1997).

Process Variable (PV) – the variables thought to have the greatest impact on the Key Quality Characteristic (KQC); (Carey & Lloyd, 1995).

Quality Characteristic (QC) – those aspects of the process which the primary customer identifies as important (Carey & Lloyd, 1995).

Run chart - A graphical, non-statistical chart that provides a running log of a process over time. They are not as sensitive as control charts in detecting special causes of process irregularities (Carey & Lloyd, 1995).

Sigma – The Greek letter σ. The symbol is used to designate the standard deviation of a population distribution (Blackstone, et al., 1995).

Simulation – a quantitative approach to decision-making. This approach is commonly used in situations in which it would otherwise be difficult to construct a real experiment. A model of the system or process is built which represents the actual model. The models controllable inputs are then manipulated to determine what affect, if any, this change would have on the output of the model (Anderson, Sweeney, Williams, 2003).

Six Sigma Quality – a term used generally to indicate that a process is well controlled, the common causes of variation exist in plus or minus 3 sigma from the centerline of a control chart. The term is usually associated with Motorola, which named one of its key operational initiatives Six-Sigma Quality (Blackstone, et al., 1995).

Span reduction – phrase coined by GE CEO Jack Welch to describe the essence of Six Sigma - a tool used to minimize the variance in a process (Smith & Blakeslee, 2002).

SPC – Statistical Process Control.

Theory Z - a description of Japanese management style applied to American companies. The theory is derived from Douglas McGregor's categorization of managers according to their assumptions regarding human nature: Theory X – in which managers assume humans are fundamentally lazy and irresponsible, and Theory Y- in which managers assume humans are fundamentally hard-working, and responsible. The Theory Z management style runs parallel to McGregor's Theory Y. The central tenet of the Theory

Z style of management is that the relationship between management and employees is not adversarial in nature (Ouchi, 1982).

Total Quality Management - a term coined to describe a post WWII Japanese style of management. The style was characterized by an enterprise-side approach to quality improvements. Since then, the term is now used to collectively describe the various methods and tools used to address quality issues (Blackstone, et al., 1995).

Type I error - the case where one concludes that there is a special cause of variation when in reality it is not present (Lee & McGreevey, 2002).

Type II error – the case where one concludes that there is no special cause of variation, in other words the variation is due to a common cause, when in reality a special cause is present (Lee & McGreevey, 2002).

Validation – examining/analyzing the outputs of a simulation model to determine if the output is consistent with data collected on the actual real-world system. Face validity involves asking experts to review results to determine the models reasonability. Data validity involves insuring that the inputs to the model are representative of the modeled system (Evans & Olsen, 2002).

Verification – examining a simulation program to ensure that the simulated model accurately represents the conceptual model and is free from logical errors. This is usually the first step in checking the usefulness of a model. Logic testing, debugging, client review, and comparing output for its realism are recommended components of this step (Evans & Olsen, 2002).

u-chart – a type of control chart. It is the ratio measure chart. The data is count data (Lee & McGreevey, 2002).

X-barS chart – a type of control chart. It is a paired control chart using the mean (X-bar) and standard deviation (S) charts. The X-bar chart reveals whether there is a special cause of variation across the time intervals. The S chart reveals whether there is a special cause of variation within each time interval (Lee & McGreevey, 2002).

XmR chart – a type of control chart. It is a paired control chart using the mean (X-bar) and moving average (mR) charts. It is also referred to as the "Individual's chart" (Lee & McGreevey, 2002).

CHAPTER 2

REVIEW OF THE RELATED LITERATURE

Business Process Improvement Measurements

Harrington (1991) states that there are essentially three major process measurements:

1. Effectiveness – the extent to which the outputs of the process meet customers' needs and expectations. A synonym for this measurement is quality.
2. Efficiency – the degree to which waste is eliminated and resources minimized.
3. Adaptability – the flexibility of the business process to handle future, or changing, customer expectations.

The effectiveness of measuring these three characteristics hinges upon how well a business defines customer needs and expectations. The "voice of the customer" (VOC), both the internal and external customer, is what the organization needs to evaluate, quantify, and document in writing. The VOC should be described in measurable terms. Only then can an organization define the way data are collected and analyzed.

Effectiveness measurements typically relate to the following service or product attributes: appearance, timeliness, accuracy, performance, reliability, usability, serviceability, durability, costs, responsiveness, adaptability, and dependability. Harrington notes that the effectiveness of any process can be improved regardless of how well designed the current process exists. The common techniques used to measure effectiveness are customer check sheets that describe how the customer views the product or service, customer feedback regarding new products or services, customer self-inspection of the product or service, surveys, questionnaires, interviews, focus groups, customer complaint analysis, and market research. The lack of effectiveness (quality) is usually easy to see and measure (Harrington, 1991).

In contrast, efficiency measurements are harder to recognize and measure. Many organizations simply overlook this measurement, and as time moves forward, efficiency usually suffers. The typical efficiency measurements are processing time (cycle time), resources expended per unit of output, value-added cost per unit of output, percentage of value added time, poor-quality cost, and wait time per unit. Among these measurements one of the most meaningful is cycle time. This is because in a typical organization the real value-added time spent on a product or service is 5% of the total cycle time. And, the focus of many improvement ideas is usually directed towards improving this portion of the total cycle time. The remaining 95% of the time, the non-value-added portion, is usually ignored. One of the key underpinnings of improving non-value-added activities is eliminating sources of error. The difficulty in measuring efficiency is that the benefits of improving this characteristic only affects the process owner, and this usually includes identifying sources of error. And, since the organization is essentially measuring themselves, many are resistant to this practice. These improvement activities are likely to be invisible to the external customer. The typical efficiency characteristics are cycle time, resources (in dollars, people, space,) per unit of output, value-added cost as a percentage of total process cost, poor-quality cost per unit of output, and wait time per unit/transaction (Harrington, 1991).

Finally, adaptability is the most difficult to measure. And, to worsen the situation, an inability to flexibly adapt to "extreme" customer situations or demands will likely result in a high customer dissatisfaction level. Harrington (1991) contributes three good ways of measuring process adaptability: measuring the average time it takes to process a customer's special request compared to standard processing times, calculating the percentage of special requests that are denied, and measuring the percentage of time special requests need to be escalated. The key is to design business processes that are intelligent. Thus, there are predefined, standard methods of satisfying customers with unusual needs and/or expectations (Harrington, 1991).

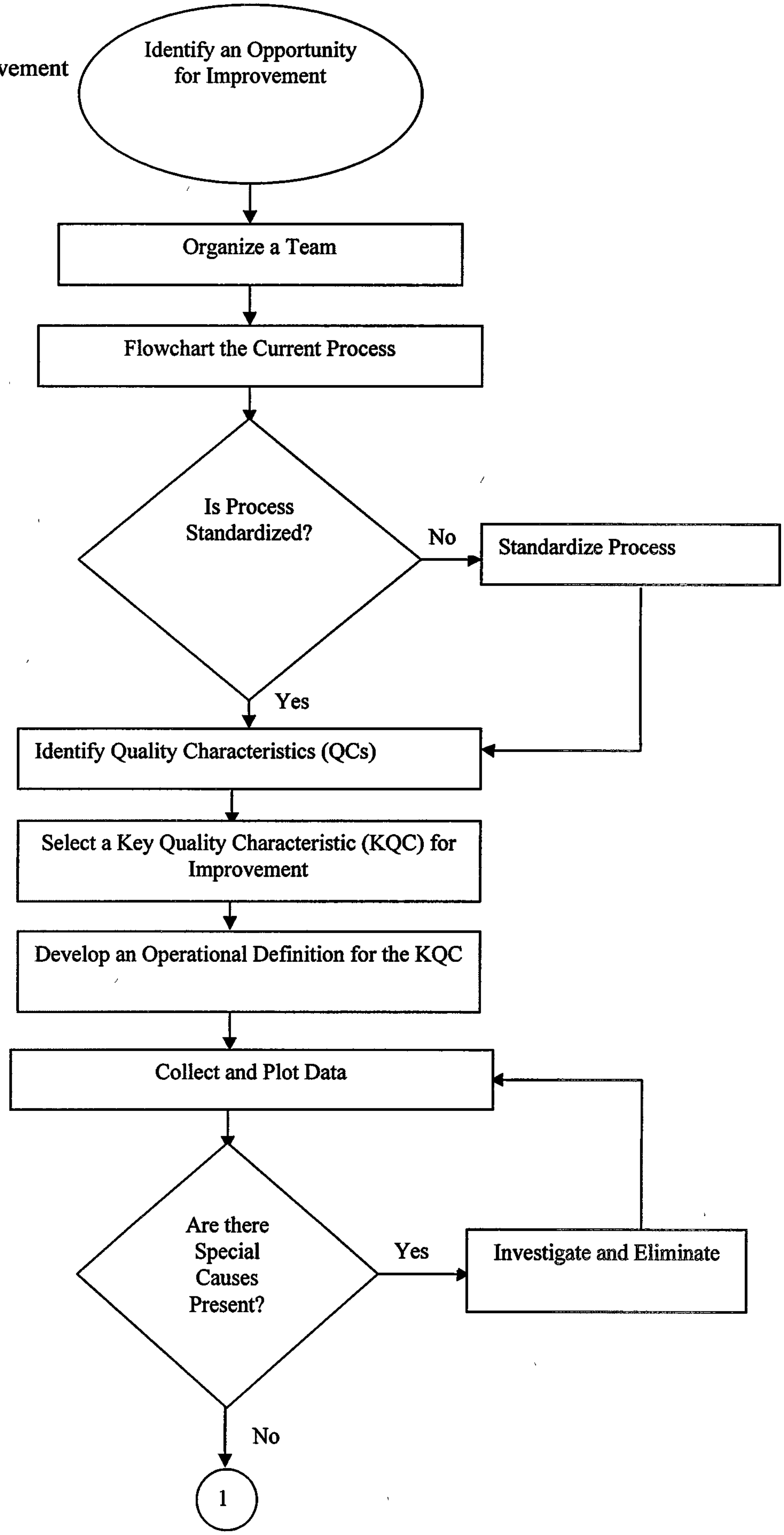
Six Sigma

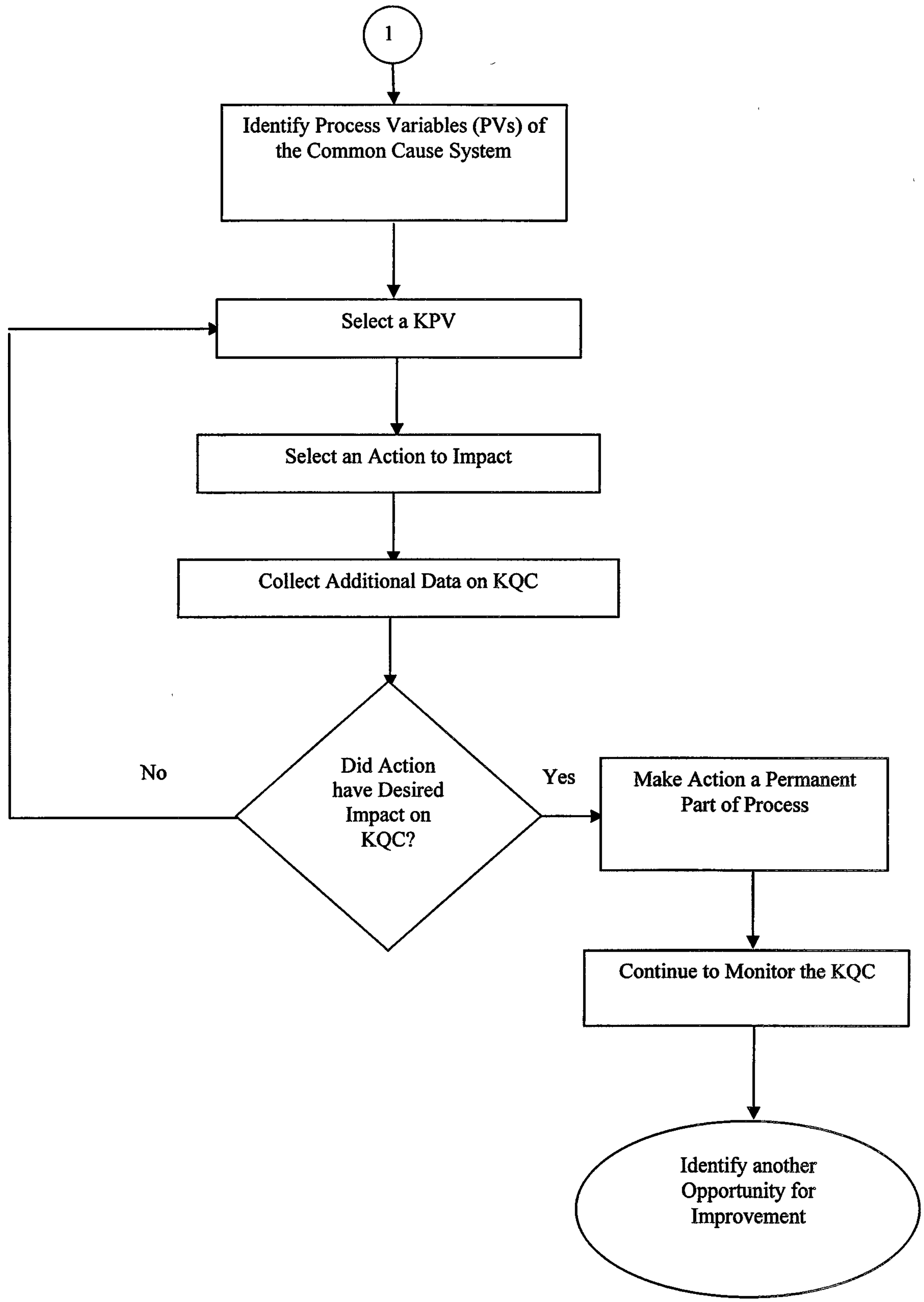
The application of statistics in the control of processes has been practiced for decades. Statistical process control (SPC) originated in the manufacturing industries and its various techniques are now ubiquitous. As a result, most of the literature regarding this topic is related to its uses and applications in the manufacturing sector. Unfortunately, the service industries were not as quick to grasp the strategic advantages of SPC. Carey and Lloyd (1995) published a book that provides a summary of the statistical, Six Sigma based tools as applied to measuring quality improvement in healthcare settings. They mention in their book that it was not until the mid 1980's that these tools were readily applied in healthcare settings. In fact, in 1990 Dr. Deming held a four-day quality conference in Indianapolis. Amazingly, of the 700 people in attendance, only 25 were from the healthcare industry (Carey and Lloyd, 1995).

The initial focus on quality used the methods and ideas of W. Edwards Deming, Joseph M. Juran, and Philip B. Crosby. The control theories and tools were used to "assure" that products met certain requirements. The problem with quality assurance (QA) techniques was that they were usually done after a product or subcomponent was manufactured. The item may not make it to the customer, but there is certainly a cost associated with the production of a non-conforming item. This cost was certainly passed on to the customer, probably without the customer's knowledge. Because of these shortcomings the quality movement shifted towards "quality improvement" (QI). The paradigm shift, from the QA to the QI approach, was what was needed to effect substantial and permanent change in the way organizations provide products and services. Improvements accomplished via the QI approach generally focuses on two strategies: 1). a reduction of the variability in processes accomplish, and 2). a shift of the process in a desired direction. In order to achieve the desired results a road map should be employed to guide the actions of the individuals involved in the process. A simple, well-tested roadmap is presented in Figure 1.

Carey and Lloyd recommend that seven preparatory steps be considered before executing data collection and analysis. The roadmap begins with identifying an opportunity for improvement. It is important to note that one of the pitfalls of the continuous improvement cycle is that many teams start with the data collection and analysis before the preparation for this step. The opportunity for improvement should originate from the external or internal customer, or both. The key is to select a process

Figure 1: Process Improvement Flowchart




1
Identify Process Variables (PVs) of the Common Cause System
Select a KPV
Select an Action to Impact
Collect Additional Data on KQC
Did Action have Desired Impact on KQC?
No
Yes
Make Action a Permanent Part of Process
Continue to Monitor the KQC
Identify another Opportunity for Improvement

that matters from the customer's point of view, not your own. There are a few tools that are commonly used to capture the customer's voice. One method is to build a focus group.

A focus group is a collection of customers that can be assembled to verbally discuss the dissatisfying characteristics of a particular process. The advantage of this method is that the issues can be probed in depth. The disadvantage is that the sample may not be large enough to accurately represent the customer population.

Another method is to conduct a survey. Well-conducted surveys usually capture a larger proportion of the customer population than the focus group method. The disadvantage to this method is that the actual survey must be carefully constructed to be able to measure the true sentiments of the population. For this reason, there are many professionally developed surveys that are offered to a variety of customers and thus are designed for specific situations. Carey and Lloyd caution that care should be taken when choosing and applying a survey.

Either of the two methods mentioned above is likely to yield many opportunities for improvement. It is important that the QI team have agreed upon a specific problem.

The second pre-data collection step involves prioritizing the opportunities. Pareto Analysis is the tool commonly used to rank the opportunities in order to identify the one opportunity that would serve as the Key Quality Characteristic for the team's improvement efforts. Pareto Analysis is named after the nineteenth century Italian economist Vilfredo Pareto who observed that a minority of people in Italy owned a large proportion of land and production resources. He observed that 20% of the people owned 80 % of the wealth. Thus, the same analysis can be ascribed to identifying the one process issue that causes up to 80 % of customer dissatisfaction. Dr. Joseph Juran applied this principle in his Continuous Quality Improvement (CQI) theory to identify the one opportunity of improvement that should be pursued first. It should be noted that the Pareto Analysis can be used at several points within the Process Improvement flowchart – for example in identifying an opportunity for improvement, selecting a Key Quality Characteristic, or for selecting a Key Process Variable.

The third step requires the analysis of whether or not a team needs to be assembled to address the opportunity. It is possible that the scope of the project is small enough to be addressable by one person. The team should be representative of all the areas impacted by the agreed upon opportunity for improvement. The team members should all agree upon what the team will and will not be doing. It is also important to define the scope of the process to be improved - where the process starts and where it ends. If the scope is large, complex, or requires urgent action, a team is assembled that is comprised of all the stakeholders in the process. This includes not only those who execute the process, but also those that have the knowledge to understand and contribute to the process. It is also possible that the members of the team may change over the course of the project as the team discovers that the complexity of the project justifies the addition of more stakeholders. Also, it should be noted that some organizations employ a trained facilitator for the team. This facilitator may be an internal staff member or an external consultant. Dr. Deming noted that the facilitator may take on the role of an "outsider" with the task of making sure the team doesn't succumb to the threats of "group think", facilitating meetings, assessing team performance, and generally keeping the project on track.

Once the team is organized and the preliminary problem definitions are in place the task of developing the current process flowchart begins. The fourth step requires that the team clarifies the current "as is" process. It is important to note that this flowchart is not a representation of how the process should work, but rather how it currently works. This includes identifying all the steps in the process. Input from all the team stakeholders is important, as it is necessary to capture all the intricacies of the current process. A flowchart or swimlane diagram would be an appropriate tool to visualize the steps in the process. This exercise may expose process differences between certain groups of employees or it may expose additional issues that need to be addressed before continuing towards the data collection stage. Also, review of the current process should reveal the problem of an unstandardized process. If for example, it is revealed that there are five different ways that the stakeholders are completing the process, this would signal an opportunity to standardize the tasks into one process. Only after the process is standardized can the team move on to the next steps in the process improvement flowchart.

A thorough, well-mapped current process will help to answer the question in the next step of the process improvement flowchart. The fifth step involves addressing an unstandardized, unclear process. And, the fifth step is to standardize the process. There must be a uniform way of carrying out the process before the team can begin to improve the process. If this is not done, there will be no certainty that any change to the process had a direct impact on the Key Quality Characteristic.

Once a standardized process is in place the team identifies the customers and determines what the customers define as the most important aspects of that process. This is step six in the process. These important aspects of the process, as defined by the customer, are the Quality Characteristics (QCs). The team sorts through the QCs and decides which one will become the Key Quality Characteristic (KQC). The KQC will become the focal point for the team. The authors note that what the customer views as important may vary from individual to individual. It is important that the team collectively choose the one characteristic that they believe is the "key" to customer satisfaction.

Once the Key Quality Characteristic is established, step seven requires that the team develop an operational definition for this characteristic. The goal in this step is to describe the KQC in quantifiable and measurable terms. It should be a clear, concise, and unambiguous operational definition of the KQC. It must specify the measurement method, equipment, and if appropriate, the criteria to be used to make measurement decisions. The operational definition should be known and accepted by all team members so there is no disagreement regarding "what", "where", "why", "when", and "how" the KQC is to be analyzed.

These preparatory seven steps assure that the data collection plan and analysis is done accurately and efficiently. Now, the team can move forward to the data collection plan. The authors make a distinction here between data and information. Data are defined as "the raw facts and figures which are collected as parts of the normal functioning of the hospital." Information is defined as "data that has been processed and analyzed in a formal, intelligent way, so that the results are directly useful to those involved in the operation and management of the hospital." It is noted that good data collection is as much an art as it is science. The data collection effort involves the development of a plan. The plan should include reasons for collecting the data, how the data will be used, and the technical details regarding how the team will actually collect the data. To answer the question "why" the data are collected, the team should attempt to plan to collect data to enable intelligent improvement upon the process. Thus, data should be collected in order to do the following:

- Understand the variation that exists in a process.
- Monitor the process over time.
- See the effect of a change in the process.
- Provide a common reference point.
- Provide an accurate basis for prediction.

Data is collected in order to conduct statistical studies that provide the basis for taking action. Dr. Deming identified two types of statistical studies:

1. Enumerative – those studies that are done on a static population for a given period of time and/or location and are designed to merely describe certain outcomes.
2. Analytic – these studies are done dynamically, are not restricted to a single point in time, focus on prediction future events rather than on describing the past, and seek to make inferences about why certain outcomes were observed and how to improve the process that produced those outcomes.

The type of study undertaken by the team should help guide them in regards to "what" data are collected, "how often" it is collected, and the sampling requirements for data collection. The KQC should be a clear indicator of what data should be collected. The type of study should help the team address the issue of how often and for how long the data will be collected. This decision determines the quality of the data. Finally, the sampling technique used should be representative of the data collection plan.

Simple random sampling is frequently used in enumerative studies and seeks to allow every member of the population to have an equal chance of being included in the study. A random number table or pseudo-random number generator will facilitate the randomization process. The disadvantages of this technique is that it does not make use of any of the prior knowledge regarding the population and it also produces larger sampling errors for the same sample size than stratified sampling techniques.

Proportional stratified random sample employs the randomization process to a stratified representation of the total population. The proportion of cases in each category or stratum of the population should be the same as that in the sample. The advantage to this approach is that the sample will provide an accurate representation of the population distribution. Thus, this technique yields less sampling error than a simple random sample. Also, the chance of failing to include members of a particular category of the population is eliminated. And finally, the characteristics of each category of the population can be described. The disadvantage of this technique is that it requires an a priori knowledge of the population stratification. One must also be aware that the cost of using this technique is higher than the simple random sampling method because it requires that the population strata are mutually exclusive and a larger sample is required in order to include a sufficient number of subjects within each stratum.

The last sampling technique discussed by Carey and Lloyd is the judgment sampling technique. This technique is the common choice for analytic studies. It is also referred to as expert, or rational sampling. The technique requires the collection of data on a series of subgroups from the population. The subgroups and time component of the data collection is usually determined by a knowledgeable expert of the process to be studied. Subgroups and be drawn by a random or nonrandom process. The samples are drawn on a continuous basis in contrast to the simple random and proportional stratified random procedures, which are drawn at fixed points in time. The judgment sample has a cost advantage over the other two samples, it requires less data, and it enables the process improvement team to take action as the data is collected over time. The disadvantage is that sampling error can not be collected. Also, inferences regarding the population can not be drawn from this sampling method. Another disadvantage is that the method requires the expertise of an expert for the process.

At this point, Carey and Lloyd include remarks regarding the use of a pilot study to test the efficacy of the data collection plan. The pilot study is also referred to as a "pretest". The objective is to apply the tools, methods, and the operational definition the team identified in the preparatory steps. The team observes the application of the data collection plan to identify shortcomings of the plan. If there are problems with any part of the plan, the team can make minor adjustments before moving forward with the data collection process.

Once the data collection plan is executed the raw data must be analyzed. The analysis of the data features a close inspection of the variation locked up inside the data. Carey and Lloyd authors provide two options for viewing variation: Static displays and Dynamic displays. Static displays show the data in a tabular form (i.e. tables, histograms, bar charts). These displays usually include central tendency measurements such as the mean, median, mode; and measures of dispersion such as the range, standard deviation, and variance. Dynamic displays are plotted on run or control charts. These tools allow a graphical display of how the data varies over time. Dynamic displays of data have some distinct advantages over static displays. One can decide if there are "special causes" of variation in the data and the displays also assist in understanding the process in order to improve further data collection and analysis.

A short historical note should be injected here regarding the frequently used terms "special cause", "common cause", "chance cause" and "assignable cause". Dr. Shewhart distinguished between two types of variation by using the terms "chance cause" for normal, controllable variation and "assignable cause" for uncontrolled causes of variation. Later in the late 1940's, Dr. Deming coined the terms "special cause" and "common cause" as applied to the same two types of variation causes (Carey and Lloyd, 1995).

Determining variation type hinges upon the actual plotting of data on a run or control chart. These charts are reviewed for "special causes" of variation in the process. Special causes of variation are due to irregular, unnatural events that are not inherent to the process. When these causes are present, a process is declared "out of control" or unstable. Thus, special causes of variation become the focus point for the loop in the process improvement flowchart that is designed to investigate and eliminate the special cause of variation. It is important to note that attempting to improve a process that contains "special causes" of variation will likely increase variation and waste resources. If a special cause of variation does not exist, then the process exhibits only "common causes" of variation and the team continues into the next phase of the process improvement flowchart. It should be noted that "common causes" of variation occur in every process. It is simply random error due to regular, ordinary, or natural causes. If a process exhibits only "common causes" of variation, then one can declare that the process is operating "in control". And, the data can be analyzed to make predictions about the future. The types and analysis of run charts and control charts is listed in the Run Chart/Control chart section of this paper. The next phase is the development of an improvement strategy.

The development of an improvement strategy begins with the identification of process variables (PVs). These are the variables that are hypothesized to have the most impact on the Key Quality Characteristic. From the list of PVs, one variable is chosen which is designated the Key Process Variable (KPV). An improvement strategy is developed around the KPV. And, an action strategy is developed around the KPV. The action is implemented and the impact to the Key Quality Characteristic is evaluated. The team evaluates the strategy and decides if the improvement produced the desired impact. If the desired impact is achieved then the decision might be to include the improvement as a regular component of the process. If the desired effect was not reached, then the team must review the original list of Process Variables, select another Key Process Variable and restart the action strategy sub-process.

Finally, once an improved process is in place it is important to monitor the process. An appropriate level of periodic monitoring will ensure that the process does not regress back towards the initial level of unacceptable performance. Once there is a sustainable level of performance another opportunity for improvement is identified and the continuous improvement cycle starts again.

Specific Six Sigma Tools

Brainstorming

Brainstorming is not a tool that is used to determine the best solution or action to take on a particular issue. It is a team-based, creative process that is used to generate as many ideas or solutions as possible. The idea is to create a non-punishing environment in which team members can submit their ideas regarding an issue. Ground rules for conducting a brainstorming are advisable. Some of the most basic ground rules are listed below:

- Brainstorming can be a fun process – there are no dumb ideas and unserious solutions should not be scorned. Creativity should be cultivated.
- Criticism of other's ideas is not allowed. It is not a debate, discussion, or political forum.
- People should be allowed to build upon other's ideas. Foster a creative environment in which the normal paradigms are challenged.
- Quantity of ideas is highly preferred - more preferred than the quality of the ideas.

The brainstorming sessions should have a facilitator that keeps the process intact. The team may be allowed to determine the ground rules for the session. It is recommended that the team make decisions regarding where the session will be held and who will participate. It is advisable to identify one person as the note taker for the group. This person should be able to write quickly so the session progresses naturally and the creativity of the session is not restrained (Simon, Effective Brainstorming, 2003).

The Cause and Effect Diagram/Matrix

The Cause and Effect (C & E) matrix is also known as the Fishbone diagram or the Ishikawa diagram. The C & E diagram is a pictorial representation of the many potential causes for a specific problem. It is a team-based problem solving approach in which the team collectively agrees on the statement of a problem. Development of the fishbone diagram progresses through specific steps in order to guard against peoples natural inclination to focus on what to do about the problem rather than analyzing the complete spectrum of issues surrounding the problem. This main problem becomes the "head" of the fish. The bones that make up the body of the fish are drawn as lines that emanate from the head of the fish. These bones represent different categories. These categories can be developed by the team depending on the situation or subject matter, but the literature recommends the following industry specific categories as starting points:

Service Industries – The 4 – Ps.

- Policies
- Procedures
- People
- Plant/Technology

Manufacturing Industries – The 6 – Ms.

- Machines
- Methods
- Materials
- Measurements
- Mother Nature – (Environment)

- Manpower – (People)

Once the categories have been identified, the team brainstorms to identify the possible causes for each of the categorical problems. These causes are smaller bones that attach to the categorical bones. Finally, for each cause identified the team attempts to supply supportive information that identifies "why" the issue exists. The "whys" become the smallest bones that are attached to the cause bones on the fishbone diagram. The next step would be to validate the root causes of the problems, perhaps with a larger or separate group of stakeholders, then prioritize the causes in order to identify the most important causes to measure (Simon, The Cause and Effect Diagram, 2003). Additionally, the C & E diagram can be represented in a spreadsheet type of matrix. The user lists process inputs and uses a scoring system to help rank the most problematic inputs.

Affinity Diagram

The affinity diagram is also called the KJ method and is named after its author Kawakita Jiro. Mr. Kawakita devised the diagram and didn't originally intend for it to be used as a quality management tool. However, it became an important tool in process improvement. In fact, the Japanese quality leader Kaoru Ishikawa recommended that the affinity diagram be used to refine brainstorming sessions. The affinity diagram is useful when the facts or thoughts of a brainstorming session were uncertain or need to be organized, when preexisting paradigm boundaries need to be crossed, if ideas need clarification, or when team cohesiveness needs to be strengthened. Basically, the diagram consists of classifying a raw list of brainstorming ideas into similar subgroups.

The process of grouping ideas should occur naturally, using the right side of the brain, instead of relying on preexisting notions of similarity. Grouping should occur quickly; initially it isn't important to define why the ideas belong together. As it progresses, one should be aware that small sets of ideas may belong in another larger group. Or conversely, larger sets may need to be broken down into smaller, distinct groups. When completed the subgroups are given titles that uniquely identify the subgroups of ideas (Saudi National Quality Committee, 2003).

Kano Analysis

The Kano Analysis quality measurement tool is named after the Japanese quality expert Dr. Noriaki Kano. Kano analysis helps in ranking requirements for different sets of customers with the goal of assigning priority to those requirements that are key customer satisfiers. Dr. Kano stated that there are four types of customer satisfiers:

1. The "Surprise & Delight" factors – those attributes that really make your product/service standout from your competitors.
2. The "More is Better" factor – small differences in a product/service may differentiate your product from others. For example, if the time the customer waits to receive your service is a few minutes less than your competitors, the probability of satisfying your customer is greater.
3. The "must be" factor – those attributes that are absolutely required by the customer.
4. The "dissatisfying" factor – those attributes that cause your customer to be dissatisfied with your product/service.

Once customers have been classified, the Kano analysis can be reapplied within each segment to further refine the understanding of the customer and their needs (Carder, 2003).

Run Chart

A run chart is a dynamic, running record of a process over time. The advantage of these charts is that they can be used with any type of data and require no statistical calculations. The disadvantage to run charts is that they can detect some, but not all, "special causes" of variation. The run chart may miss "freak" points since it employs the use of the median as the measure of central tendency. Thus, the chart is not sensitive to the absolute values of the data points that make up the chart and there is a possibility of missing a "special cause" of variation. A run chart can be constructed using the following steps:

1. Construct a horizontal, x-axis. Label it by the time intervals used to collect the data.
2. Construct a vertical, y-axis. Label it with the appropriate data type being measured. Allow the scale to extend plus/minus 20% past the range of the collected data to allow for future data points.
3. Plot a minimum of 15 data points in sequential order.
4. Connect the points on the graph with a solid line.
5. Determine the median for the data and construct this horizontal line on the graph.

Once the run chart is constructed one can move on to the analysis of the data. The analysis must include a definition of what is considered a "run". A run is defined as one or more consecutive points on the same side of the median. When counting the number of runs on the chart, data points that fall directly on the median are ignored. An alternate method of counting runs on the chart is to count the number of times the sequence of data points crosses the median line and add one. There are four tests that applied to the run chart to determine the existence of a "special cause" of variation. The first test is used to determine if there are too few or too may runs in the data.

Test 1

Calculate the number of "useful observations" by subtracting the number of data points that fall on the median from the total number of data points. Find this number in the first column of the Run Chart Limits Table shown in Table 1. If the number of runs in the data fall below the lower limit or above the upper limit, this is a signal of a "special cause" of variation. This test is designed to identify the case of too few or too many runs in the data.

Table 1

Run Chart Limits

Useful Observations	Lower Limit	Upper Limit
15	4	12
16	5	12
17	5	13
18	6	13
19	6	14
20	6	15
21	7	15
22	7	16
23	8	16
24	8	17
25	9	17
26	9	18
27	9	19
28	10	19
29	10	20
30	11	20
31	11	21
32	11	22
33	11	22
34	12	23
35	13	23
36	13	24
37	13	25
38	14	25
39	14	26
40	15	26

Test 2

Case 1: For N < 20 data points – if 7 or more data points occur in one run, this is a signal of a "special cause" of variation.

Case 2: For N $\geq$ 20 data points – if 8 or more data points occur in one run, this is a signal of a "special cause" of variation.

This test identifies a shift in the process.

Test 3

Count the number of consecutive data points that are increasing or decreasing. Include in the count any data point on the median. Compare this count to the values in the Run Chart Consecutive Ascending/Descending Table shown in Table 2.

Table 2

Run Chart Consecutive Ascending/Descending Table

Total Number of Data Points on Chart	Number of Consecutive Ascending/Descending
5 to 8	5 or more
9 to 20	6 or more
21 to 100	7 or more

A "special cause" is identified if the number of consecutive ascending or descending points equals or exceeds the limits shown in the table.

Test 4

Fourteen or more points in a row forming a “zig-zag” or “saw-tooth” pattern exhibits the existence of a “special cause” of variation. A positive test usually signals a lack of stratification in the data or the presence of tampering with a machine or process.

Control Charts

Control charts have the added feature of control limits which allow one to inspect the capabilities of a process more accurately. It also assists in predicting future behavior of the process. The control chart is set up in much the same manner as the run chart – with the time sequence plotted on the x-axis and the Key Quality Characteristic variable on the y-axis. The data points are connected by a straight line. In contrast to the run chart however, the measure of central tendency for a control chart is the mean for the data. The mean is identified on the chart by a straight, horizontal line. Control charts also have an Upper Control Limit (UCL) and a Lower Control Limit (LCL) which are drawn as straight lines horizontal to the mean. Both control limits help to identify if the process is capable of producing desired results and in identifying “special causes” of variation.

Control charts were first developed by Walter A. Shewhart, of Bell Laboratories, in the 1920’s. He is credited with applying the principles of the Normal distribution to the task of identifying “special causes” of variation. The normal distribution is a symmetrical, bell-shaped curve with the central tendency measures of the mean, median, and mode in the same location. The variance or dispersion of the data is measured using the equation for standard deviation (usually denoted as SD, or the Greek symbol sigma; σ). Six measures of standard deviation encompass approximately 99.73% of the area under the Normal distribution curve. Thus, statistically only about 0.27% of the data points fall outside plus/minus 3 standard deviations from the mean. If data points fall outside the plus/minus 3 sigma limits, a "special cause" of variation can be identified.

When determining how one is to detect "special causes" the researcher or engineer may choose to use plus or minus 2 sigma. This entails that 95% of the data within a normal distribution will fall within two standard deviations from the mean. This also means that 5 % of the data points will fall outside the limits. So, there is a greater risk of concluding that a data point falling outside the upper and lower limits in the distribution is a "special cause" of variation when in reality the data point may be a common, chance occurrence of variation. This type of mistake is termed a Type I error. With a Type I error, the researcher/engineer is likely to "tamper" with a process that may be already stable. In contrast to the Type I error, a Type II error is one in which the researcher/engineer concludes that a data point is a "common cause" of variation when in reality is may be a "special cause" of variation. This leads to "under controlling" the process. In order to minimize the risks of missing "special causes" of variation and incorrectly declaring "common causes" as "special causes" the use of the plus/minus 3 sigma control limits is used. In other words, this minimizes the total risk of making Type I and Type II errors. Shewhart declared "we must use limits such that through their use we will not waste too much time looking unnecessarily for trouble." In healthcare however, we must set the limits in accordance with the seriousness of the particular application. For example, if we are measuring patients as part of a screening process for a potentially fatal medical prognosis, it may not be ethical to set control limits at plus or minus 3 sigma. It may be safer to set the control limits at plus or minus 2 sigma in order to protect against making a Type II error.

Some of the rules relating to the use of control charts stems from the statistical measure of standard deviation. Each of the following tests should be applied independently, to **each side of the mean**, to detect "special causes" of variation:

1. One data point outside the 3 sigma limits.
2. Two out of three successive data points at $\pm$ 2 sigma limits.
3. Four out of five successive data points at $\pm$ 1 sigma limits.
4. Eight successive points on either side of the mean.

These tests apply to the **entire control chart**:

1. For N < 21 data points – Six or more data points in a row steadily increasing or decreasing.

   For N $\geq$ 21 data points - Seven or more data points in a row steadily increasing or decreasing.
2. Fourteen successive points alternating up and down forming a "zig-zag" or "sawtooth" pattern.
3. Fifteen consecutive points within $\pm$ 1 sigma.

The use of these tests presumes that the data is normally distributed. The researcher/engineer must carefully review the data to validate the assumption of normality.

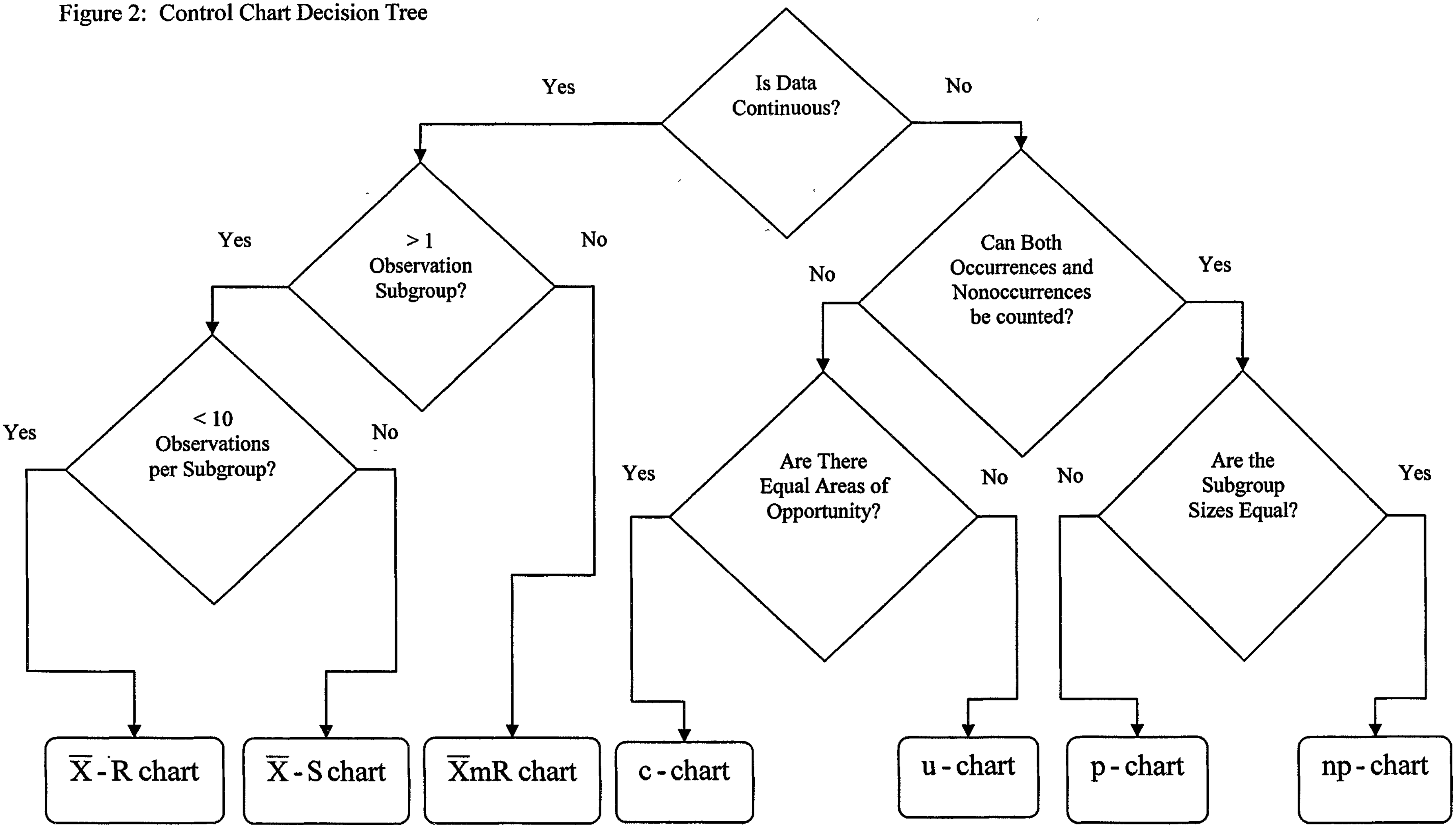
There are several types of control charts. Choosing which one to use depends upon the type of data encountered, the number of observations per subgroup, the ability of the researcher to count the occurrence or nonoccurrence of an event, the number of subgroups, and the equality of event opportunity. The control chart selection decision can be simplified by the use of a flowchart as shown in Figure 2.

Data types are either continuous or discrete. Continuous data are measured on a continuous scale and are either Interval or Ratio data types. Discrete (attributes) data is data that can be counted and organized into discrete categories. There are two types of discrete data. The first type is data for which one can count both the occurrence and nonoccurrence of an event. This allows the researcher to calculate the percent "defectives". The percent defective measurement is simply a ratio of the occurrences or nonoccurrences in the numerator divided by the total number of events that took place. The second type of discrete data involves the situation where the researcher does not know the number of nonoccurrences. The data, or "counts", in these types of measurements are usually referred to as "defects".

The decision on which of the continuous data control charts to use hinges upon whether or not there exists more than one observation per subgroup. A subgroup is a sample of data pulled from a stream of data produced by a process. Subgroups should be selected so that if a "special cause" exists, the chances for differences between subgroups will be maximized and the chances for differences within a subgroup are minimized.

For example, in healthcare settings subgroups may be defined by shift. In manufacturing, subgroups are commonly defined by machine. The $\overline{X}$ - S and $\overline{X}$ - R chart are used in those cases where the researcher collects more that one observation per subgroup. The $\overline{X}$ - R chart is then the appropriate tool to use when the

Figure 2: Control Chart Decision Tree



number of observations is equal to or greater than ten. If there is only one observation per subgroup, the $\overline{X}$mR chart is the appropriate tool to use.

The decision regarding which of the discrete data control charts to use first hinges on the question regarding whether both the occurrences and nonoccurences of an event can be counted. If one of the two cannot be counted, the c-chart and u-chart are the appropriate tools. The c-chart is used in the situation when there are "equal areas of "opportunity". An equal area of opportunity means that any two measurements must have an equal chance of a particular outcome. If the chances are not equal the data must be turned into rates in order to be comparative. The conversion of the data point into a rate is accomplished by dividing the count of occurrence by its own total area of opportunity. The u-chart is used when the areas of opportunity are not equal.

The p-chart and np-chart are used when both occurrences and nonoccurrences can be counted. The p-chart is used in those situations when the subgroup sizes are unequal. The np-chart is used in those situations when the subgroup sizes are equal.

Lean and Six Sigma

Many professionals in the industry would agree that Lean manufacturing and Six Sigma techniques are complimentary to each other. However, one should note that there are cases where businesses and corporations have launched one or the other, but not both, and conversely where the two techniques have been employed simultaneously. So, it is important to recognize the subtle differences between the two techniques, how they are viewed in the business community, how they can be combined successfully in a comprehensive attack on waste, and the potential incompatibility of the Lean techniques applied in heath care settings.

Historically, Lean manufacturing is not a new concept. Henry Ford recognized the importance of eliminating non-value added time during a production process – he was quoted as saying "one of the most noteworthy accomplishments in keeping the price of Ford products low is the gradual shortening of the production cycle. The longer an article is in the process of manufacture and the more it is moved about, the greater its ultimate cost." Amazingly, the Toyota Motor Corporation of Japan eventually used Ford's ideas as a strategic, competitive tool. Shortly after World War II ended Toyota engineers Eiji Toyoda (the founder of Toyoda), Taiichi Ohno, and Shigeo Shingo worked to improve upon the American model of automobile manufacturing. Together they refined manufacturing techniques with the goal of eliminating or reducing tasks that were non-value added. They knew that if the customers were aware of the cost of each activity in the manufacture of an automobile, they certainly would not be willing to pay for those activities that did not add value to the final product. Their manufacturing techniques became known as the Toyota Production System. American manufacturers, realizing the competitive pressure from overseas, began to reintroduce some of the Toyota techniques into their factories. These techniques were named "Lean manufacturing" in America (Alukal, 2003).

Waste is the enemy in the Lean enterprise. Depending on the source one reviews, there are seven or eight types of waste. The eight types of wastes (called *muda* in Japanese are as follows:

1. Overproduction – making more product faster than the next operation or process needs it.
2. Inventory waste – any supply of raw material, work in process (WIP), or finished goods, that is in excess of one unit.
3. Defective product – any material or product that is characterized as excess, obsolete, or defective. Also, any product that requires rework or additional inspection.
4. Overprocessing – any extra processing that does not add any real value for the customer.
5. Waiting – any form if idle time spent waiting for material, machinery, manpower, information, or measurement.
6. People – the waste involved in not fully using an employee's mental/creative skills or their experience.
7. Motion – any unnecessary movement of people, tools, and machinery.
8. Transportation - any unnecessary movement of materials within a factory.

In comparison to the eight wastes recognized by the Lean technique, proponents of the Six Sigma technique recognize three types of waste – defects, variation and unwanted products. Interestingly, the building blocks that support the identification and elimination of waste in the Lean technique also support the goals of waste elimination in Six Sigma techniques (Alukal, 2003).

The Lean building blocks are used to introduce, sustain, and improve a Lean production system. The common building blocks are as follows:

- 5S – the foundation of workplace organization and standardization. The five Japanese terms – Seiri (sort/discard), Seiton (arrange/order), Seison (clean/inspect), Seiketsu (standardize/improve), and Shitsuke(believe/discipline), are sometimes referred to in English as Sort, Set in Order, Shine, Standardize, and Sustain. Also, Henry Ford had a similar notion he coined as "CANDO" – an acronym that stood for clean, arrange, neatness, discipline, and orderliness (Parks, 2003).
- Visual Controls – the entire manufacturing system should be able to be understood at a glance. Tools, materials, processes are clearly positioned/marked so that there is no mistaking the status of each item or process.
- Streamlined layout – the entire plant is physically designed to optimize the pull of the product and information through the facility.
- Standardize work – specific methods of assembly and processing are designed to eliminate sources of variance and unwarranted motion. Tasks are completed safely in accordance with ergonomic standards.
- Batch size reduction – the optimum lot size is one unit. This reduces all types of inventory and allows stakeholders to detect potential problems early. If a lot size of one is not feasible, then the goal is to reduce the batch size to be as small as possible.
- Teams – regardless of the type of work that needs to be completed, the team concept is fundamental in the work environment.
- Quality at the source – the operators themselves inspect for quality. A work piece passed down the manufacturing line is known to be of acceptable quality.

- Point of use storage - material, work in process, tools, work instructions, and information are stored where they are needed.
- Quick changeover – the flexibility of being able to change tooling and fixtures rapidly in order to produce a range of products in small batches.
- Pull and kanban – the product being produced is "pulled" downstream through the factory by the end customer. An upstream supplier does not produce anything until a downstream customer signals a need for their product via the use of a kanban system.
- Cellular of flow - the physical linkage of workstations or cells in an efficient manner in order to maximize added value and minimize transport waste.
- Total productive maintenance – the discipline of periodically maintaining tools, equipment, workstations, and the facility to maximize production effectiveness.

Many of these building blocks can be used without the statistical underpinnings that are evident in the Six Sigma methodologies. Thus, Six Sigma practitioners should view the building blocks within the Lean techniques as enablers for Six Sigma projects. In other words, the Lean techniques can be used to pick the "low hanging fruit". Once this fruit is cleared, improvement teams can better identify the other "fruit" within the branches that will serve as the focus for the statistical tools within Six Sigma projects (Smith, 2003).

Herein lays the fundamental difference between the use of Six Sigma and Lean techniques. The Lean techniques are biased toward action and intuition. The users of Lean methodologies are faster to act upon a perceived problem. In contrast, the users of the Six Sigma techniques may spend six months or more on a single project. This may result in the perception that the momentum for transforming a process is lost. By combining both the Lean and Six Sigma tools users can quickly eliminate obvious problems and begin processing the more difficult problems within the organization (Smith, 2003). Caution should be exercised however when applying Lean techniques in healthcare settings. It should be obvious that lower levels of inventory, or batch size reductions could have disastrous effects in emergency situations. If for example, a hospital was deluged by patients in an emergency situation it would not be effective to stock small amounts of medicines, or to treat critical patients in lot sizes of one unit. So, Lean techniques should be applied thoughtfully and selectively in any healthcare environment.

Six Sigma Case Studies

The literature review shows that the applications of Six Sigma tools in healthcare industries are somewhat scarce, but many hospital executives are turning to Six Sigma after becoming frustrated with slow gains from traditional quality programs. The Froedtert Hospital in Milwaukee, Wisconsin; the Medical College of Wisconsin; and the American Society for Quality formed a partnership program aimed at reducing medical errors and enhancing patient safety at Froedtert Hospital. Their initial focus was not on cost drivers. The consortium's purpose was to run a trial application of Six Sigma tools in a healthcare organization. Their Six Sigma projects were aimed at reducing errors associated with analgesia pumps, continuous intravenous infusions, narcotic sedation in postoperative patients, insulin therapy, the handling of laboratory specimens, and in reducing the number of falls on a rehabilitation unit. They were initially frustrated with lab turnaround times and the first team projects were assigned to address this issue.

Some of the projects results were as follows:

- 25.68 % reduction of downtime minutes.
- 73 % improvement in average number of transactions per day.
- Implementation of a rapid-response lab near the intensive care units to improve turnaround time.
- 21.86 % improvement in the time to draw to the results of the lab test.
- 35.23 % improvement in the time of lab receipt to results.

The project also implemented some improvements that could be characterized as "Lean" type improvements – standardization of order entry options, and color coding of stat labs for improved turnaround time with the main laboratory. Cathy Buck noted that the implemented changes were focused on reducing medical errors as "medical errors are very costly, with payers and the public demanding change, so there was a strong business case (Scalise, 2001)." The early successes of the Six Sigma project teams led the hospital to include Six Sigma methodology as an important, strategic tool in their business plan. In addition, JCAHO is supportive of the Six Sigma activities at the hospital. Overall, the hospital's managers realize that a data-driven approach like Six Sigma provide clear opportunities for process improvements (Pelletier, 2003).

Six Sigma efforts usually include financial measurements in order to determine how well individual Six Sigma projects impacted the bottom line of the organizations financial statements. For example, Commonwealth Health Corporation, of Bowling Green, Kentucky, realized an annual savings of $276,188 in improved billing processes. They also realized an annualized savings of $595,296 in its radiology expenses in 18 months. Their President and CEO, John Desmarais, stated that since February of 1998 the corporation has invested $1.25 million in Six Sigma efforts, but realized a savings of $2.9 million (Scalise, 2001).

Six Sigma methods were used to optimize the reporting and delivering of radiological examinations in a Belluno, Italy hospital. The hospital's study used the Six Sigma five-step problem solving process DMAIC – define, measure, analyze, improve, and control to define the problem and pinpoint those elements of the process that were crucial to quality. They focused on the radiological report creation process – from the end of examination to the time the report is made available to the patient. Their goal was to provide radiological reports to their inpatients within 36 hours and to their outpatients within 72 hours. An analysis of all the different tasks involved in this process showed that 73% of the total process variability was due to the reporting phase (end of examination to the end of reporting) and 17% was due to the distribution phase (report available to the staff to report available to the patient). Thus, they concentrated their efforts on the two tools the hospital was using for report creation - dictaphone and voice-recognition systems. It was found that the median time for report delivery using the voice-recognition system was 45 hours, whereas dictaphone reports were taking 96 hours. The conclusion was that the exclusive use of voice-recognition systems could potentially improve the process by 50 hours. Their decision was to abandon the dictaphone process. Also, inspection of the report delivery process revealed that the root cause of excessive process variance was due to individual employee behavior patterns. This was attributed to a lack of a clearly defined process map. Solutions for this problem were discussed between the stakeholders of the process and a clearly defined process map was developed. Interestingly, this study had a positive impact on not only the external customer, but also provided greater satisfaction levels between the hospital's internal customers (Cavagna, et.al, 2003).

The Emergency Department at the Decatur Memorial Hospital in Decatur, Illinois used Six Sigma techniques to decrease the initial wait cycle time for customers as measured by the time difference between entry of the facility until the point when they are seen by a doctor. They also benefited from a decreased total length of stay (LOS) cycle time and a decrease in the number of patients who leave the hospital without being seen (LWBS) by a doctor (Pexton, 2003).

The 388-bed Rapides Regional Medical Center in Alexandria, Louisiana started a Six Sigma project in August of 2001. Their emergency department experienced 40,000 visits per year. Their projects yielded reductions in LWBS patients and LOS. In addition, the emergency department stakeholders set up an Express Admit Unit for admissions and they developed a Fast Track Center for non-acute patients during non-peak hours. They were also able to expand their efforts into the radiology department by reducing the radiology cycle time. Astoundingly, the potential impact to their cost structure was an estimated annual savings of $957,000 (Pexton, 2003).

The Good Samaritan Hospital in Dayton, Ohio used Six Sigma methodologies to lower their emergency department LOS from an average of 326 minutes to 180 minutes. They also lowered the amount of time their facility was on reroute/diversion status from 107 hours in February 2002 to only 6 hours in the same month one year later (Pexton, 2003).

The Northwestern Memorial Hospital in Chicago, Illinois improved throughput and room utilization by 20 percent. Their patient wait time was reduced more than 40 percent. And, their customer satisfaction scores went up into the 80th percentile as evidenced by the scores on their Press Ganey patient satisfaction survey (Pexton, 2003).

The Franklin Hospital Medical Center in Valle Stream, New York reduced their bed turnaround time by almost 50 percent. The average emergency department wait time decreased 25 percent and the amount of LWBS patients also decreased. They also reported improved financial gains - quarterly revenue increased by $56,448. This quarterly gain corresponds to a $225,792 annual increase in revenue (Pexton, 2003).

Statistical Measures in Healthcare Quality Assurance

A case study was reported by Davis (1991) in which the management of a complex, university-owned, teaching hospital Operating Room was forced to take quick action in order to address problems with inefficiency and internal political strife. It was realized that the managers needed to reshift their focus from their normal duties to providing support to quality management efforts.

The problem in the operating room of this hospital was that they were receiving an increasing number of complaints concerning inefficiencies in booking cases. The concern was heightened since the hospital was about to add fourteen new surgical beds, surgical faculty was being added, and the hospital needed to handle 2 – 3 additional surgeries per day to meet the financial strategic plans. The nursing and anesthesia teams were under duress trying to complete each days demands. All the stakeholders in the process felt that their needs and goals were mutually exclusive. “Managing by the facts” was not stressed; instead the stakeholders felt that politics was more important. A Quality Improvement approach was implemented in order to face the problems.

Many quality improvement tools were used to solve the problem. An Operating Room committee was formed as a quality improvement team and they began to study the process and their related issues using a fishbone diagram. From this, the team formulated three major goals for the project. They also formed three sub teams - a Task Force (steering committee), and two subordinate task groups. Most of the individuals selected to serve on the teams were those people who were viewed as being positive-oriented, non-negative, and it was thought that they possessed a higher potential to contribute honestly and effectively towards the goal. However, some individuals with strong opinions were part of the team make-up, and it was theorized that their addition helped promote diversity to the group. This helped to negate the problems related to group think and helped to break down we-they attitudes.

Historical data, written policies, opinions, OR schedules, were gathered to address the problem. Room utilization calculations and specific cases were graphically viewed in a Gantt chart to visualize delayed starts, gaps between cases, mid-afternoon lulls, and unused schedule times. Four priorities emerged from this exercise. Histograms, fishbone diagrams, brainstorming, Pareto diagrams, precedence diagrams, and flow charting tools were used to address the four priorities. As a result the team identified some of the tasks that were taking place in series, and implemented changes for certain tasks to be done in parallel. In addition, they recommended that some tasks take place before the patient arrived in the operating room. Potential time savings of 10 – 15 minutes were identified. After five months, on-time starts improved by 25 minutes, room utilization rates improved by 5%, staff cost decreased, and increased throughput led to increased admissions and revenue. Maybe more importantly, the physicians and staff believed that improvements in the internal working relationships reduced workplace stress and the resulting improved patient care levels would provide more significant results. Champions emerged from the project and the professionals within the hospital began to "manage by the facts." Some teams remained focused on the OR issue in efforts to achieve further gains and many new quality initiatives were spawned from the original project (Davis, 1991).

Many of the traditional tools used by industrial or management engineers blend well with the tools used in Total Quality Management (TQM) concepts. Kantutis et.al, 1991, describes a case study in which mixtures of quality tools were used to improve the quality of a healthcare service. The study took place in the Outpatient Laboratory at Rush-Presbyterian-St. Luke's Medical Center (RPSLMC) in metropolitan Chicago, Illinois. The lab processed approximately 30,000 outpatient visits annually. The project was initiated when directors and managers requested that the management engineering group identify ways to reduce patient waiting times and improve productivity.

The project used the Shewhart PDCA cycle as the framework for the quality improvement project. This PDCA cycle includes four separate phases – Plan, Do, Check, and Act. A team-based approach was used and the project goal was defined to improve patient satisfaction (primarily with respect to waiting times). An additional problem the team decided to address was thought to be caused by workplace environment factors – the problem being the courtesy of the registration personnel. The data collection phase consisted of a voluntary, patient survey that used the laboratory services over a ten-month period. The patients were asked to classify the amount of time spent waiting to be registered and the amount of time spent waiting for their particular procedure. The initial goal of the team was to improve the waiting times to 10 minutes for registration and procedures.

Next, a flowchart was constructed that detailed the process that patients traveled through registration and procedure. Then, data were collected over 5 weeks on the actual wait times patients experienced. A time stamp machine was used to record arrival and completion times. Also, the card was stamped at each intermediate process step by the person in charge at each substation. The card was turned in to the registrar once the patient had completed their visit. Thus, the card provided a complete audit trail of the process and times experienced by each patient. In addition, a time study was done on samples of each type of patient to determine average registration service times.

From the data collection phase four key areas contributing to patient dissatisfaction were identified. It was found that patients complained more about the time they spent waiting for the registrar than for the time they spent waiting for individual procedures. A control chart was used to track the variability in registration waiting times. The purpose of this was to determine if there were "common" or "special causes" of variation in the registration process. Interestingly, the first control chart showed that the data did not follow a normal distribution. So, the engineers transformed the data using a cube root transformation. Once transformed the data were analyzed appropriately and accurately. The control chart showed that the registration waiting times were in control. There were no special causes of variability. This was important to the study since the existence of a special cause of variability would necessitate that the team solve that problem first before making changes to the registration process. Since there were only common causes present (inherent to the process) the team could move forward and focus on designing changes to the registration process.

The redesign phase employed the use of a Lotus based queuing model and a time study to examine the impact of different alternatives to the problem. In addition, the team had the registration personnel participate in the development of an affinity diagram to organize ideas surrounding the waiting time issue. This exercise helped surface other non-patient based issues that may indirectly affect the registration times. Categories of interest were prioritized and then addressed individually. Once the redesign of the process was accomplished, the "check" phase of the improvement cycle could commence.

Patient questionnaires and surveys were used to gather satisfaction data from the patients experiencing the new process. Also, waiting times were recollected using direct observation. Control charts and time studies were used to reanalyze the variation in the process. Average waiting times were recalculated to inspect for changes. Overall, the study highlighted the fact that traditional industrial engineering techniques could be successfully merged with quality improvement tools. The role of a healthcare industrial/management engineer has changed from one that typically focused on making quality improvements to one that serves as a quality advisor for the organizations own quality teams. Thus, the engineer is one that guides others through the various quality improvement stages – coaching the correct use of problem solving techniques, data collection, and data analysis (Kantutis et al., 1991).

Management Engineers Jay Post and Sly Goldberg conducted a study in an emergency department at the Santa Clara Medical Center in California. The problem encountered by the facility was excessively long lengths of stay which caused overcrowding and refusal of ambulance traffic. Their methodology in approaching this problem focused on identifying the "critical path" of the length of stay elements for their patients. Their goal was to improve the emergency department throughput and decrease the patient length of stay (LOS).

In excess of 400 patients were tracked over ten days in October of 1990. Data were collected by the study engineers using direct observations for each of the LOS components. Additional data collected included the data on the Emergency Department Log and Chart. This data were used to construct a matrix of the different patient types and their associated LOS components. This helped to reveal which patient types and LOS factors had the most impact on lengths of stay. An analysis of these figures showed that an addition of a "Stat Lab" machine would not be cost effective. However, they were able to identify other areas for improvement that would net savings equal to the cost of the "Stat Lab" machine. In addition, it was noted that the engineers could initiate a project aimed at reducing lab turnaround times and the time component from the end of the last service rendered to discharge (Goldberg et al., 1991).

In 2001, Hasin et.al, published an article that reported the outcome of a total quality management project at Muang Petch Thonburi Private Hospital in Thailand. The aim of this study was to use the results of customer satisfaction surveys to drive quality improvement projects in the hospital. The project goal would be to eliminate factors of dissatisfaction. This was important to the success of the hospital since many competitors were vying for ISO 9000 Quality Management System certification in efforts to differentiate themselves from the competition. Their data collection and methodology included the use of a customer questionnaire given to two different sets of patients – inpatients and outpatients. These two sets of patients were subdivided into 3 subgroups: a personal payment group, a company's contract payment group, and a health insurance company payment group. The customers scored the hospital on various factors: return intention, cleanliness, food, courtesy levels, and the service levels of doctors, nurses, and officers. The SPSS cross-tabular computational facility was used to identify relationships between questionnaire factors. Satisfaction scores were calculated and ranked regarding 18 different quality factors. A weighted overall satisfaction score was calculated for each patient. The statistical analysis of these scores involved the use of a One-Way Analysis of Variance (ANOVA) test to determine if there existed a significant difference in the overall satisfaction scores between the types of payment subgroups. This analysis was done separately for the inpatient and outpatient groups. The results showed that there was not a significant difference in satisfaction levels between the payment type subgroups in the outpatient category. In contrast, the study found a significant difference between the payment subgroups for the inpatient category, $F(3,135) = 5.304$, $p < 0.010$. There is a problem with this reported statistical result as the between degrees of freedom is erroneously reported as 3. There were three subgroups which means that the between degrees of freedom should have been reported as 2. This may have altered the results, but the effect of this error cannot be determined, as we do not know the true origin of the error. If it was simply a transcription error - and if the Sums of Squares and the other degrees of freedom were accurately reported, this would have heightened the significance level of the inpatient category test. The same error is reported in the outpatient ANOVA table. And, if we make the correction for the between degrees of freedom, the ANOVA test for difference actually produces a significant result. However, for the purposes of this article review, we will focus on the results of the inpatient results. The Post Hoc tests showed that the personal payment group had significantly lower overall satisfaction levels than the health insurance group. This statistical result is the basis, or the starting point, for quality improvement projects. The One-Way ANOVA helped to classify the patients into satisfied and dissatisfied categories.

From these categories, the improvement team created a Pareto Analysis chart that identified the top five factors that contribute to dissatisfaction. Thus, the Pareto Analysis is the tool used to prioritize problem-solving efforts. Then, a Cause and Effect analysis was performed to identify potential causes for the top five dissatisfaction problems. This study reported the use of brainstorming sessions, held by the nursing team, to identify causes and sub causes to the problem. From these tools they identified five main causes of dissatisfaction within the inpatient population: the work system, computer system, the nurse aid, the cashier (an officer of the hospital), and hospital policy. They also identified many sub causes related to the five main causes. From the Pareto and Cause and Effect tools the improvement team then decided to use a control chart to monitor a specific process.

For the inpatient group the team decided to use a p-chart to monitor unsatisfactory service levels. For 30 days in September, 1999 they collected data by observing one patient each day. They specifically used the p-chart to graph the patient's dissatisfaction level in the waiting time after discharge. The waiting time after discharge was thought to be a main cause for dissatisfaction, as determined by the Cause and Effect Analysis, and one of the root sub causes was the cashier's service level. At the end of this 30-day analysis the p-chart reveals certain days where the post-discharge process is out of control. The team then focused on what happened on each of these days that the process went out of control. Their findings were that in the case of personal payment the printing facility causes delay. Thus, the suggested solution would be to fix the printing capability problem within the discharge process. In the case of the insurance payment group the lack of a well-defined and efficient process for exchanging information between the hospital and the patient's insurance company caused a delay in the post-discharge process. Through benchmarking, the team found that other hospitals arrange for fax claims which serve to reduce the time required to discharge patients.

This article provided a full view, from start to finish, of the various quality improvement applications used to solve an organization problem. Even though this hospital had a good overall level of service quality, they realized that in order to stay competitive within their market they needed to make improvements. In conclusion, the authors note that several important changes need to take place in any quality improvement effort. The entire quality improvement process and solution implementation require that employees undergo an attitude change regarding nonconforming services. Training is the keystone to changing behaviors in efforts to improve service quality. And, training efforts must be inclusive of everyone within the organization. Training helps to internalize the belief in the tools used to identify organizational weaknesses. Without a strong belief in "doing things right the first time and every time", a long-term change in your customer satisfaction levels is usually not realized. In other words a paradigm shift must take place in which the behaviors and the style in which the organization operates make a conscious change in the way they employees conduct their daily business. Top-level management should support and drive the paradigm shift. As the leaders of the organization these managers must institute a quality policy. In fact, the leaders of the Muang Petch Thonburi Private Hospital decided to implement ISO 9002 policies. The authors also make the point that a limitation to this study was that the satisfaction measures were derived from external customers. The authors suggest that employees' behaviors and attitudes also be measured in order to attain better quality problem resolution.

Speed in the delivery of a service is critical in today's healthcare environment. Generation X'ers and Baby Boomers are demanding that services are rendered quickly and that includes their healthcare. If their expectations are not satisfied they will take their business elsewhere. St. Michael Hospital in Milwaukee, Wisconsin has witnessed this phenomenon and has had to fight to regain customers. The hospital served the northeastern part of the city for 50 years, but in 2002 the Wisconsin Health and Hospital Association reported that St. Michael had registered a 4.8 percent drop in admissions. At the same time their competitor Columbia St. Mary's was experiencing a 4.3 percent surplus at their Milwaukee campus and a 0.9 percent increase at their suburban Ozaukee campus. People were driving out of town to receive healthcare. St. Michaels realized that they had become complacent and inadaptable to the fast-changing market in their area. They needed to refurbish their business operations. Bruce James, an industrial engineer by training, was named president of St. Michael hospital in November of 2002. His 22 years in the healthcare industry and his industrial engineering training played a crucial role in the renovation of St. Michael Hospital. Mr. James led the renovation by applying industrial engineering techniques, renaming them "performance improvement" practices, on a day-to-day basis (Averett, 2003).

One of the first problems to be addresses was the inefficiency of the emergency room. Excessive wait times and long patient turnaround times were the norm. New technologies were applied to the problem, but Mr. James stated that simple process changes were the most effective. For example, a simple redesign of the admission process - which eliminated one phone - facilitated physicians in spending more time with the patient instead of handling administrative issues. In addition to improving the admission process, changes to testing procedures and the way in which patients were moved through the hospital further improved cycle times. As a result, the average cycle time to move a non-trauma patient through the emergency room dropped from 187 minutes to 120 minutes (Averett, 2003). In conclusion Mr. James asserts that continuous process improvements are essential to healthcare organizations. The key word here is "continuous" as a one-time application of improvement techniques is not sufficient in preparing a business to be better able to adapt to future business environments. Mr. James stated that "we are trying to find out what we can do better. We don't accept anything as being perfect anymore. There's always some kind of improvement that can be made on a process (Averett, 2003)."

Some studies are using quality improvement tools that are complimentary to Six Sigma practices. For example, many healthcare organizations are applying Lean manufacturing techniques in efforts to improve quality, service, safety, and productivity. General Motors is a major customer for the Detroit Medical Center (DMC) hospitals. In

1994, GM chose the radiology oncology center at DMC's Harper University Hospital as a healthcare test site for implementation of its Lean manufacturing principles. Since that time other DMC hospitals have jumped on to the "lean" bandwagon. The emergency room department at DMC's Detroit Receiving Hospital and Huron Valley-Sinai Hospital participated in lean manufacturing projects designed to reduce waiting times and streamline patient flow. They expanded on these initial successes adjusting ER protocols that allow treatment of patients to begin in triage, bedside registration, and quicker patient admittance to the treatment areas (Kolodziej, 2001).

Computer Simulation in Healthcare

There are several examples of studies that employ the use of simulation software in efforts to document processes within a healthcare organization. Zhao (1996) used ARENA simulation software, version 1.1, to study and refine the Level I emergency room operations at a major Air Force base in San Antonio, Texas. The significance of this study was that the simulation models would not only serve as a tool to improve operations at the primary base being studied, but also serve as a prototype for modeling the effects on two similar trauma centers in the area. The vision was that it would serve as an experimental platform from which a larger, more complex model could be designed and studied. This would ultimately benefit the military personnel and civilians in the San Antonio, Texas area as the three Level I facilities work cooperatively to provide trauma care for these people.

The data for this study were captured using existing records, observations, and interviews. Historical emergency department records were used to describe patient arrival rates and patient acuity (4 categories) distributions. A total of 13,486 patients were in included in the study – these patients had visited the emergency room in a three-month time span in 1995. Administration records were used to determine the department's physical resources such as the number of doctors, nurses, rooms, and beds. Three hundred eighty-one patient log sheets were reviewed to capture lab and x-ray frequencies. A previous time study was used to understand the typical service times associated with such tasks as registration, triage, and nurse service times. However, physicians' service time was determined through direct observation. Finally, Zhao reported that lab/x-ray turnaround times were collected by interviewing nine staff physicians. The physicians estimated the minimum, maximum, and most likely time to receive a lab or x-ray result. These times were then input into a commonly used PERT/CPM formula to develop average and variance time estimates for lab/x-ray turnaround times.

Once the base "as-is" model was developed, validation of the model was required in order to insure the computer simulation model accurately reflected the actual system. Emergency department physicians and other staff members were allowed to view the animated simulation for validation purposes. In addition, the simulation output data was investigated for differences as compared to actual "real world" data using a Paired t-test with the result being that there was no significant difference found.

Different scenarios were then created using the simulation software that allowed Zhao to analyze "simulated" changes to the emergency room department. The analysis involves comparing the output of the scenario model to the output of the base, "as-is" model to determine if certain changes to the system produce a desirable improvement over the base model. Scenario 1 investigated a proposed "fast-track" concept in which patients belonging to categories 1 and 2 (lower trauma levels) would be diverted to another clinic effectively freeing up time, space, and resources in the emergency room. The result was that the average time for all patients in the system reduced by 19.17%. Category 1 and 2 patients experienced the largest reduction in the amount of time spent in the system. And, another benefit of this scenario would be that the category 3 and 4 patients were able to seize resources more quickly. In addition, it was noted that the utilization rates for the emergency room resources (doctors and nurses) went down. Scenario 2 was developed to explore this result.

Scenario 2 removed one nurse from the resource pool. But, it was found that as the utilization rate for the remaining nurses went up; the patient waiting time also went up. This scenario was regarded as impractical.

In Scenario 3 a model was built to explore the potential condition of the closing of one of the three trauma centers serving the San Antonio area. The model goal would be to help predict the workload on the remaining trauma centers. The input modeled in this scenario was an increase of category 4 patients by 50%. This model yielded a slight increase in the time a patient spent in the system and waiting time. The utilization rates of the doctors increased approximately 6-7% and the trauma bed utilization rate increased by almost 30%.

In his conclusion Zhao reported that one of the difficulties encountered during the study was the use of a questionnaire. Originally, a questionnaire was used in an attempt to query physicians regarding doctors' service times. The data gathered using this tool showed that the physicians' responses were not precise and varied greatly from individual to individual. As a result the questionnaire was scrapped and Zhao resorted to directly observing 120 patients in order to capture doctor service times. He also had problems with various aspects of the software: its inability to handle concurrent processes and an inflexibility in dealing with reassigning resources to higher priority patients – for example once a doctor was assigned to a patient, that doctor could not be released temporarily to work on another patient.

Mowen (1997) used MedModel software, version 3.2, to simulate and analyze the daily operations of Brooke Army Medical Center's (BAMC) Level I trauma care facility in San Antonio, Texas. From the customer perspective, this retrospective study focused on determining patient waiting times and throughput times per patients' acuity level categories (Categories 1-3, 1 being the lowest criticality level). From a business perspective the study captured the resource utilization and system capacity of the trauma center.

The data collection stage of this study captured patients' type, triage time, treatment time, and overall time via a randomized sample by social security number. The data originated from the original Emergency Care and Treatment Form 558 as filled out per each patient, BAMC's trauma registry, and staff interviews. Mowen also used direct observation techniques to verify and supplement the data collected. The statistical software package SPSS, version 7.0, was used to generate the descriptive statistics needed as inputs into the MedModel simulation software.

Flowcharting was used to graphically represent the flow of patients through the care process. BAMC's head nurse, two trauma center doctors, one trauma center nurse, and two acute care clinic screeners verified the flowchart for accuracy. This tool was used to design the base model for the simulated process in MedModel.

Once the base model was built, the simulated process was run for 84 days. It is noteworthy that Mowen actually ran the simulation for 12 weeks and 1 day – the 1 extra day was used to allow the simulated model to achieve a "steady state" condition. Then, verification of the model entailed using the simulated data to compare to the actual arrival rates for the three-month period of data collection. An Independent t-test showed that the simulated statistics did not significantly differ from the actual statistics ($p<0.05$). In addition the patient triage type, total time in system, and the patient throughput times for the simulated model were tested against actual values using a one-sample t-test and all showed no significant difference ($p<0.05$). Once the model was verified, Mowen could then run several "what-if" simulated scenarios to compare to the base model.

Scenario 1 was run to view the effects of the closing of a nearby hospital – Wilford Hall. At the time of the study it was noted that a combination of decreases in defense spending and an increase in civilian patients to the military BAMC hospital could significantly impact the trauma patient load (category 3 patients) on BAMC's services. Specifically, the model was run with a 50% increase in category 3 patients. The model showed that the impact would result in significant increases in the average throughput times for category 1 patients ($p<0.0001$), but not significantly impact category 2 or 3 patient throughput times. Thus, the potential closing of nearby Wilford Hall would not significantly elevate the throughput times for critical category 3 patients. Next, the utilization rates were reviewed for significant changes. The nurse, resident, and staff medical doctor utilization rates all increased significantly ($p<0.0001$). Thus, hospital administrators would need to review and possibly adjust the staffing levels if there were a

50% increase in category 3 patients. The simulation also revealed that there was a significant increase in trauma bed utilization ($p<0.0001$). The final conclusion for this scenario was that the administration should be most concerned with personnel resource utilizations.

Scenario 2 in Mowen's study stemmed from the observation that there were low utilization rates (below 25%) for 3 out of 16 treatment beds. So, a model was developed to simulate the removal of 3 beds while holding constant all other arrival rates and resource levels. The results were that there was no significant change to the average throughput times for any of the three patient categories. Also, there was no change to the staff's utilization rates. The trauma bed utilization rate was not changed, but the treatment bed utilization rate was increased significantly ($p<0.01$). Normally, this finding would have prompted the administration to remove these three beds, but it was found that 2 of the 3 beds were designated as suture beds and could not be removed. These beds were not identified as being different from the treatment beds in the initial resource identification phase and may have introduced a bias in the results. Therefore, the final conclusion was that only one treatment bed could be removed.

Scenario 3 was run as a combination of Scenarios 1 and 2. The results showed a significant increase in the throughput times for category 1 and 2 patients ($p<0.01$). In contrast to these patients, category 3 patients showed a decrease in throughput time but it was not significant. The same impact was shown for total time spent waiting for each of the three patient categories. The explanation for this phenomenon was that more time was spent treating the critical category 3 patients at the deleterious expense of category 1 and 2 patients. The utilization rate review showed that the nurse and staff medical doctor rates significantly increased ($p<0.0001$). Finally, the treatment and trauma bed utilization rates were examined. Both categories increased significantly ($p<0.0001$). Overall, the scenario 3 recommendation to BAMC was to increase the staff by one nurse, resident, and staff medical doctor. The other resources were adequate to meet the potential 50% increase in category 3 patients and the removal of 3 treatment beds.

Mowen mentions the difficulties that were encountered during this study. He cautions that the researcher must understand the types of data needed by the simulation model before entering the data collection phase. Data were collected that was not needed, and conversely data had to be collected midstream once it was realized it was needed to build the model. Also, the author recommended the use of interviews instead of surveys to collect data from the staff. It was stated that no matter how clearly a surveys questions were constructed, there are a few staff members that would misinterpret the function of the question and answer the question differently than expected. In regards to constructing the physical layout of the workplace for MedModel, it was recommended that this be generated from an existing AutoCad drawing instead of attempting to build the layout within MedModel.

The Brooke Army Medical Center (BAMC) was the focus of an additional computer simulation study, performed by Merkle in 1999, that focused on determining the impact of changes their facilities needed to undergo. In 1993, the Department of Defense was formulating strategies that would allow their facilities to compete effectively in the managed care business environment. The managed care program, called TRICARE, was designed to improve patient access, ensure quality of care, and control healthcare costs. Because of these program changes BAMC was facing cost-containment pressures and a shift in the business focus from inpatient to outpatient care.

BAMC's main problem was that they were experiencing an increase in the primary-care workload for the elderly population. In many cases this set of customers were experiencing chronic conditions which demanded more healthcare resources. Also, in general the managed care plan enrollment was increasing. Overall, the mix of the patient acuity levels and patient load was straining BAMC's primary care clinics. As a result their customers were experiencing a dissatisfying level of care and the number of complaints regarding BAMC's primary clinics was increasing. From a Pareto analysis of the scores gathered from a patient satisfaction report for BAMC's clinics, it was found that the Family Care Clinic had the highest complaint rating. The BAMC leadership requested a study that focused on improving efficiency and patient satisfaction at the Family Care Clinic (FCC).

Inefficiencies in the configurations of the FCC was thought to be the causal factor for poor access, elevated patient lengths of stay (LOS), high patient wait time, and inappropriate resource utilization. Since BAMC had no standard management tool to predict the effect of making changes to clinical resources, they decided to employ the use of computer simulation model.

The first step undertaken in the development of the model was to establish the goals and objectives of the model. This helps in providing a focused set of objectives by which the study will be executed. The second step was to plan and formulate the model. This entails collecting appropriate data in order to build the baseline "as-is" model of the FCC. A flow chart of the patient flow through the facility was constructed and evaluated for accuracy by the chief of the FCC and the head nurse. From this flowchart a list of output performance measures were identified. From this list the following important output measurements were determined to be of value to the study: Total time the patient waits until seen by a provider, total time the patient is in the clinic, Screener idle time and utilization, Provider idle time and utilization, Screening room utilization, Exam room utilization, and the total number of patients departed. In the third step of the study, the background data were collected via different methods: a time study, personal interviews and observations, and interviews with the staff to detail work hours, shifts, and breaks. Patient data were collected from historical records in BAMC's database systems. This data provided valuable information regarding the number of patients seen by the clinic per appointment type per month and the number of patients seen/scheduled for each physician per month. Another important input to the model was the floor plan of the clinic which was provided by the head nurse and imported into the MedModel version 4.2 software.

The fourth step involved the development, verification and validation of the baseline models. The model development was done incrementally, adding process detail and complexity in a stepwise fashion. As each clinical process was modeled it was debugged and verified before adding another level of complexity. Two baseline models were built – one to simulate Monday and Thursday extended-day operations, and another for Tuesday, Wednesday, and Friday normal-operations.

The fifth step involved the creation of different experimental "what-if" models and analyzing the results. Several models were built, each changing a specific aspect of the organizations resources or processes – reorganizing the allocation of certain resources, creating a new team concept, changing the patient screening process in which Licensed Vocational Nurses' (LVNs) duties in a patient screening process and eliminating the Screening room, and the evaluation of a new screening process without the addition of headcount.

The results showed that in all the experimental models it was important to have the correct mix and amount of resources. There was an optimal ratio of exam rooms to the number of LVNs to support the primary care physicians. Depending on the strategic goals of BAMC, the models showed that they needed to add one to five additional primary care physicians, four to eight LVNs, and five to thirteen for exam rooms. One of BAMC's options was to consolidate one of their family care clinics with their adult primary care clinics. However, executing this option would have only netted one additional primary care physician and five exam rooms. Therefore, when comparing this option to the experimental model it was obvious that this would not be an effective solution. They would still need to add resources in order to realize their goals. However, one of their experimental models showed that the facility could increase patient visits by 30 % and still realize a decrease in the total patient length of stay (LOS) by 10 minutes and increase primary care physician utilization rates (Merkle, 2002).

Cook (1999) used MedModel software, version 3.5, to simulate a Level II Trauma Facility in the Pediatric Emergency Center of Brackenridge Hospital in Austin, Texas. She developed a base model using the simulation software that represented the activities and processes in the Children's Emergency Center. Once the base model was verified and validated, different scenarios were developed to mimic changes in the resource levels inherent to the system. The simulation software was then run and observed for significant impact on the efficiency of the system.

In Scenario 1, the physician schedule was changed. The simulation was run and compared to the base model. The results were that the resource utilization rates for the experimental scenario were significantly lower than those of the base model ($p<0.05$). Also, the patient Length of Stay (LOS) and waiting times in the new model were significantly lower that the base model ($p<0.05$), except for patient customers to the Minor Emergency Clinic (MEC) which were significantly higher ($p<0.05$). But, the increase in the MEC was thought to be due to the increased efficiency in the treatment area which resulted in a higher, steady state of patients in the MEC.

In Scenario 2, the Scenario 1 model was changed to incorporate an additional two treatment beds. The simulation was modified to convert a supply room into a two-bed treatment room. This resulting model yielded no significant difference to the center's throughput times or waiting times ($p>0.05$). But, it did result in a significant decrease in the physician utilization rate ($p<0.05$). However, it was noted that the physical change to the hospital layout was not justified due to the expense and the fact that the reduction in the physician utilization rate in Scenario 2 was not as great as the reduction yielded in Scenario 1. In fact, the physician utilization rate for Scenario 2 was significantly higher than the rate for Scenario 1 ($p<0.001$).

In Scenario 3, the addition of a dynamic resource was added to both of the previous models. The dynamic resource was the addition of one 8-hour nursing shift during historically peak patient volume times, from 3 p.m. to 11 p.m., with the nursing resource being allocated to specific treatment rooms. The technician and nursing utilization rates were significantly decreased ($p<0.05$). The simulation results also showed that the waiting times and throughput times were significantly decreased for certain patient type categories ($p<0.05$). The patient type categories significantly impacted were the ambulatory urgent, non-urgent Emergency Medical Services, and ambulatory non-urgent patients.

Based on the findings in this study the Children's Emergency Center (CEC) took steps to relieve patient volumes by redefining the process for the Minor Emergency Clinic. The hospital changed the categorical types of patients that were treated within the various departments within the CEC. This helped to alleviate some of the process problems that emerged during high peak demand times on the system. Finally, the conclusion mentioned that the related literature on this subject is scarce, so the preparation and data collection proved to be the most time consuming part of the study. A survey was used to collect data from the staff members of the hospital. The return rate was dismal at 10%. Also, historical patient data were collected from the existing medical records. Since the medical records were inconsistent or incomplete this added a level of difficulty to the formulation of the base model that was unforeseen.

The literature review revealed a third simulation modeling application, which also involved a healthcare operation within Brackenridge hospital in Austin, Texas. Spahr (1999) modeled the delivery of emergency care within the adult emergency department using MedModel simulation software version 3.5. The goal for her study was to analyze average patient waiting times by patient type, the average throughput times by patient type, resource utilization rates, and how these times and rates are affected by changing process flows or resource levels.

Data were collected from 11 days of historical records, which resulted in 1776 records. This data were used to describe the number of patients arriving by acuity level (patient type), treatment times, waiting times, and throughput times. The managers of the clinic reviewed this data for verification purposes.

In addition to the customer data, the scheduling patterns for doctors, nurses, and technicians were collected from the emergency department staffing records. On-site observations, interviews, and surveys were used to gather information regarding treatment and service times for physicians, nurses, and technicians. Service times for lab work, x-rays, and special imaging were collected from the laboratory and radiology departments. The distribution of these services per patient type was also collected.

The data collected were used to build the simulation model. The model was then verified against flow diagrams and also verified by emergency department administrators. Validation of the model involved running the simulation for one week and replicating the model for 12 weeks. Thus, validation of the model encompassed 12 weeks of data. T-tests were also run to validate that there was no significant difference between the model outputs compared the actual medical record and observational data.

Spahr then ran four experimental, simulated scenarios and tested these against the baseline model. The goal was to determine if the experimental changes to the emergency department's systems resulted in significant improvements over the baseline model. The first scenario added a treatment technician to the 3 p.m. to 11 p.m. shift. This resulted in a significant decrease in the average length of stay (LOS) for non-urgent walk-in patients ($p<0.001$). In addition, the average waiting times (in the waiting room) for both non-urgent and urgent patients decreased significantly ($p<0.01$).

Scenario 2 explored a physical layout change in which one of the radiology waiting rooms would be converted into a waiting room for non-urgent and urgent patients waiting to be admitted to the hospital. The results showed that such a change would not significantly reduce waiting times and the model actually showed that it would increase throughput times. Thus, the benefits of computer simulation proved quite worthy as it yielded the quantitative evidence needed to make a potentially expensive decision. In this case the optimum solution was that the hospital not pursue this change.

Scenario 3 explored the impact of converting the radiology waiting room into three treatment areas for minor care patients. The model showed that average waiting room times and throughput times would decrease significantly ($p<0.001$). It also showed that the utilization rates would increase negligibly.

Scenario 4 provided an interesting example of the ability of computer simulation to explore different combinations of several proposed solutions. The scenario was run combining scenario 1 and 3 – adding a treatment technician during the peak hours and converting the radiology waiting room into treatment rooms. This combinatorial model yielded a significant reduction in average waiting room times ($p<0.05$). The average length of stay (LOS) for minor care and non-urgent patients were also reduced ($p<0.01$).

Much like Cook's study, Spahr's study ran into some of the same data collection issues. Spahr found that it was quite time consuming to sift out the correct data needed for simulation purposes from the historical patient records. Also, in the attempt to collect data from staff members, a survey was used. Once again, the survey response rate was low. It was surmised that collecting data directly from the staff members through interviews would have lessened the chance of questions being misinterpreted.

A ProModelPC simulation model was developed to study the impact of physical and personnel changes at William Beaumont Hospital in Troy, Michigan. The Nuclear Medicine Department requested the study in an attempt to assess proposed operation plans that would fit their long-range business plans. Specifically, they wanted to model the changes due to the addition of an imaging camera to their Thallium department, adding an imaging camera in their main department, relocating the computer processing function, dedicating a technician to their pharmacy department, and dedicating a technician to their computer processing function. The decision to implement these changes hinged upon the ability to quantify the impact of these changes upon the maximum number of patients, optimal patient schedule, optimal staff schedule, number of full-time employees required, ideal distribution of technician tasks to maximize productivity, staff utilization, resource (room and equipment) utilization, and average length of stay (LOS) per patient type.

A "current scenario" model was built and compared to existing departmental data. Verification of the model involved a comparison of the simulation output to known values for patient time in the department, room utilizations, department closing time, and the percentage of patients undergoing certain activities. Once the "as is" model was verified, this base model was modified in order to assess the efficacy of proposed changes. The researchers evaluated 18 different models. The results showed that some of the proposed changes would benefit the Nuclear Medicine Department (Waters, 1991).

The MedModel simulation software was also used to simulate two different clinical laboratory areas in Texas. The MD Anderson Cancer Center (MDACC) in Houston Texas used the software to analyze their hematology laboratory. Specifically, the model was used to evaluate the impact of a MICRO 21 (automated microscope) on turn around times (TAT) and employee utilization rates. The employees were performing manual differential counts on blood smears. The simulation model was validated with good results – both the predicted TAT and employee utilization rates correlated well with actual values. The model was then used to predict a 20% reduction in the amount of labor required to perform 550 manual differential counts and a 75% improvement in the TAT in the hematology laboratory (Lele, 1999).

The second clinical laboratory to apply the MedModel simulation software was the hematology and chemistry laboratories at the University of Texas Medical Branch in Galveston Texas (UTMB). Specifically, they used the model to simulate robotic processes in their laboratories receiving and processing areas. The model was validated and used to predict potential improvements in TAT and labor utilization. The results showed that the addition of robotic processes did not significantly improve TAT and only showed a marginal gain in labor utilization. The advantage to using a computerized simulation tool is this case was that the organization avoided the high costs of conventional trial and error experimentation. Obviously, the intelligent managerial choice would be to decline the purchase of robotic processes for this application (Lele, 1999).

In 1998, Leahy led a commissioned study at the newly created Breast Health Center in San Diego, California. This center was a part of the Navy's Medical Center health system. The center provided a multitude of medical and social services designed to provide a one-stop medical center for those patients that required breast care. Previously, these patients had to visit several separate clinics in order to receive complete care. In addition to the benefit of having a single, comprehensive breast care center the military health system was also challenged to provide care that was superior to civilian care in terms of patient satisfaction, cost-effectiveness, and quality. The view taken by the military was that the center needed to operate at a high level in order to survive the next decade of change and increasing competition. Their goal was to optimize the care given to their patients and to maximize physician utilization rates. Patient waiting times and provider utilization served as indicators of the clinic's efficiency. These indicators were chosen since excessive waiting times delay active duty and civilian military personnel from returning to work and families. Any type of delay was viewed as an indirect cost of the healthcare visit! And, a low provider utilization rate represented wasted manpower dollars. They decided to use MedModel software to simulate different clinic scenarios in order to optimize their operations (Leahy, 1998).

The Naval Medical Center was a teaching facility which presented some unique challenges in modeling patient flow and the use of resources in the clinic. Some patients were seen first by a resident or intern, and then by a staff physician. Patient evaluation times varied as, in some cases, two or more providers would examine the patient and then discuss diagnostic and treatment options. The clinic also had a physical restraint in that there were only four treatment rooms. The formulation of the base "as-is" model required an understanding of the patient flow through the clinic under these restraints. Data were collected from several sources – time and motion studies, clinic staff input, and clinic operating procedures. The base model was constructed and validated by showing the model to clinic providers. Model stability was demonstrated through the use of running the model through a series of model repetitions. Once the base model was solidified, 27 alternative models were generated that explored different combinations of staff (2 - 4 providers), trainees (5 – 7 individuals), and examination rooms (5 – 7 rooms). For each of the 27 models provider and space utilization and patient waiting times were reviewed by commanding officers for the clinic. The model proved helpful in addressing existing barriers to efficiency, physical expansion limitations, and personnel limitations. The end result was that the commanding officers took actions to convert a store room and a laboratory into exam rooms. This raised the total number of exam rooms from four to six. Also, the mix of staff providers and trainees was adjusted to provide the appropriate levels of care in the Breast Health Clinic. The adjustment of providers also allowed some personnel to be activated in other areas of the hospital. Thus, the medical center was better positioned to appropriately serve not only the Breast Health Clinic patients, but also patients consuming services in other areas of the hospital (Leahy, 1998).

The St. Luke's emergency room had a serious problem with long patient waiting times. Often, the average was over 3-1/2 hours. MedModel simulation software was used to analyze the entire emergency department system. One of the problems that were attacked was the relatively low utilization rate of the nursing staff. Modifications to the hospital processes resulted in a length of stay (LOS) decrease of 40 percent. For this organization, this LOS decrease equated to an increase of several million dollars in annual revenue (ProModel, 2003).

Similarly, the Miami Valley Hospital was able to reduce patient wait times and length of stay (LOS) by roughly 40 percent using MedModel simulation tools. The solutions generated resulted in an increase of an additional $2 million dollars in revenue without making physical changes to the facility or increasing staffing levels (ProModel, 2003).

CHAPTER 3

METHODS

Preparatory Methods

CTMC's Emergency Department is a complex environment - there are many business processes, and subprocesses, each with several inputs and outputs. These processes are run continuously – 24 hours a day, and 365 days a year. Also, it is important to recognize that there are many functionally organized teams that must work together in order to service their customers – the patients needing emergency healthcare. In addition, the patients themselves are complex – each with their own unique expectations and needs. It is unlikely that two or more patients undergo the exact same set of processes during a normal business day. Therefore, due to the complexity of the business processes, the scope of the study – which involves the entire Emergency Department, and the fact that the study includes two quality tools – Six Sigma and Simulation, it was beneficial to recruit as much help as possible. The study team consisted of a Six Sigma black belt, 4 post-graduate students, and 1 undergraduate student. All of the study team members went through 2 days of hospital orientation during the last weeks of August and the first week of September, 2003. Once the orientation was complete the study team members were allowed to observe CTMC's emergency department processes. The study members took general notes regarding processes employed in treating patients and their visitors, observed problems, potential areas for improvement, staffing levels, names of key personnel, sources of data, general layout of the facility, and the equipment used to process patients. This allowed the study team members to gain a basic level of understanding for CTMC's Emergency Department processes, and how patients flow through these processes.

Six Sigma

Development of the Project Team

The development of the Six Sigma portion of the study required the inclusion of CTMC's own employees in quality improvement efforts. The Six Sigma philosophies integrate quality into the day-to-day activities of every employee. Thus, in order to implement a lasting business culture it is important that the leaders of any organization support the strategies and vision behind Six Sigma projects. An initial meeting was held on October 6, 2003 in which the methodologies and goals of Six Sigma and Simulation projects were introduced to CTMC's leaders. The scope and potential need for resources were also discussed. The set of leaders in attendance included the CEO, Director of Support Services, Vice President of Nursing, Emergency Department Clinical Nursing Manager, Director of the Emergency Department and Informatics, Manager of Management Information Systems, and the Emergency Medical Director. The leaders agreed to embark on a cooperative effort - between the hospital, the university, and SBTI Incorporated - to make quality improvements within the Emergency Department. Once this agreement was made, an additional goal of identifying the internal Six Sigma Project Team leaders was discussed. Two leaders of this team were identified – the Director of the Emergency Department and Informatics and the Emergency Department Clinical Nursing Manager agreed to lead this internal team.

DMAIC

Once the Six Sigma Project Team was identified, the five DMAIC steps could be initiated. Blackbelt Six Sigma champion, Maria Madrigal, created a Microsoft Project Gantt chart that was to serve as the project management tool throughout the study. This chart was invaluable to the Six Sigma Project Improvement Team in managing activities and maintaining the correct focus from meeting to meeting.

On October 17, 2003 the initial Six Sigma Project Team meeting was scheduled to be held at the hospital. The two internal project team members, as identified in the October 6th introductory meeting, attended this meeting along with the researchers. Several items were discussed during this meeting. The identification of financial measurements to be included in the study, identification of internal Project Team members, identification of the "voice of the customer (VOC)" and the "voice of the business (VOB)", and the development of a Murphy's Analysis were completed.

VOC

The hospitals Gallup Poll data were to serve as the "voice of the customer". Since the reporting of Gallup Poll results lag actual performance, an alternative VOC measure was investigated. It was discovered that there was an internal CTMC survey that could serve as a quicker source of VOC data. This internal survey is completed daily, by a CTMC employee, via telephone, and within a day of the patient's actual service date. The survey is a ten-question questionnaire in which the customer is asked to rate their satisfaction level for each question on a Likert scale. The Likert scale used ranges from 1 to 4. The ten questions are listed below:

1. Did you feel that the ED staff was attentive to your needs?
2. Did you feel that the ED staff was responsive to your requests?
3. Did you feel that the ED staff demonstrated care and compassion?
4. Did you feel that the ED staff provided you an adequate explanation of medications and procedures?
5. Did your family members feel like they were kept informed of your progress?
6. Did you feel that the ED staff respected your privacy/confidentiality?
7. Did you feel that your brief interview with the triage nurse was completed in a timely manner?
8. Did you feel that your lab and x-ray procedures were completed in a timely manner?
9. If you experienced a delay, were you kept informed?
10. Did you feel that the discharge instructions were adequate?

SIPOC Map

On October 24, 2003 the Six Sigma Project Team met to begin construction of a SIPOC map. This meeting included additional Project Team members consisting of CTMC stakeholders representing the major internal suppliers and customers to emergency department processes. The Project Team members would build a SIPOC map by focusing on the top 5 or 6 high level steps in the Emergency Department processes. These top-level processes would be listed in sequential order and be described by action verbs. Then, the team members would list the Inputs to each process – what goes into the process - and list the Outputs to each process – what comes out of the process. The Inputs and Outputs to the SIPOC map was to take into consideration both the internal and external customers and the descriptions of each item was to be listed as nouns. In addition, three to five sub-processes were listed under each major Process step. The sub-processes list what happens within each process step. Finally, the Process steps, Inputs, and Outputs would be used to create the next tool in the Six Sigma methodology- the Cause and Effect Matrix (C & E Matrix).

Cause & Effect Matrix

The C & E Matrix tool is used to prioritize where to focus improvement efforts. It is built in an Excel table format with the major Process Steps and their respective Inputs listed in rows. The team reviews the Outputs from the SIPOC map and rephrases the Outputs as measurable requirements. These are then listed across the top of the table as column headers. Each measurable requirement is also assigned an output rating score. Each Output was scored on a scale of one to ten. Higher scores meant that the requirement was of prime importance to the customer or the business. Thus, the voice of the customer and the voice of the business help to guide the Project Team in formulating the requirement ratings. Next, the team assigns correlation scores between each of the Process Inputs and each Output requirement. The scores assigned could have only one of four levels:

0 = No Correlation

1 = The process input is slightly correlated to the output requirement.

3 = The process input is moderately correlated to the output requirement.

9 = The process input has a strong correlation with the output requirement.

Finally, the sub-scores for each Process Input are calculated by cross-multiplying the respective rating of importance to the customer and the correlation score for each cell in the Process Input row. Each of the sub-scores are added together to yield a total score for the Process Input. The highest total score identifies those Process Inputs that are the most important in explaining the variation in the Process Outputs. These Process Inputs are used in the Failure Modes and Effects Analysis (FMEA).

Failure Modes And Effects Analysis (FMEA)

The next step in the DMAIC process is the construction of the Failure Modes and Effects Analysis (FMEA). The FMEA is the primary tool for risk assessment. The inputs would include the results from the Murphy's Analysis, SIPOC, and the C & E Matrix. The outputs would yield a list of defects to be measured, a prioritized list of actions to improve processes, and the basis for a process control plan. The FMEA is best constructed with full participation of the Project Team. FMEA construction was scheduled for December 2, 2003.

The FMEA would be constructed in an Excel format. Each of the critical Process Inputs identified in the C & E matrix are transferred to the FMEA – each Process Input serves as a header for the rows in the FMEA. The team would then describe the Failure Mode – what can go wrong with the input?, and the Potential Failure Effects – what is the effect on the outputs? Then the team would assign a Severity Level score (1 – 10, with a score of 10 representing the most severe impact) for each Process Input. Next, the team would describe the Potential causes of the Failure Mode. And, the team would assign an Occurrence score (1 – 10, with a score of 10 representing a very likely occurrence) for each Potential cause of the Failure Mode. Next, the Current Controls are discussed by the team and entered into the FMEA. The team then assigns a Detection score (1 – 10, with a score of 10 representing the case where the detection of the cause or failure would never occur). Finally, Risk Priority Number (RPN) is calculated by multiplying the Severity, Occurrence, and Detection scores together for each Process Input row. The RPN is the output of the FMEA and serves to prioritize process improvement actions. High RPN scores represent a prime opportunity for improvement efforts. The Process Inputs identified in the FMEA serve as the focus for the Analysis and Process Improvement stages of the Six Sigma DMAIC methodology.

Power Analysis and Risk of Type I Error

A power analysis would be employed to determine the correct sample size in anticipation of using an Independent t-test to check the efficacy of Six Sigma improvements. The power analysis would be performed using both manual and software calculations. In addition, any statistical analyses would use an alpha level of 0.05.

Historical Data Collection

In order to provide the descriptive statistics needed to build the "as-is" simulation model and to provide a "before" Six Sigma improvement measurement of LOS performance, the hospital ER log was used to gather information. The ER log is basically a summary of every patient that enters the Emergency Department. Patients may enter the Emergency Department via two routes – by checking themselves in at the first ED stop (at the triage station, a non-EMS arrival), or by being delivered via emergency/law enforcement services (at the EMS arrival entrance). For each patient entering the Emergency Department, an Emergency Room (ER) chart is generated. This chart not only documents the patients personal information it also serves as a repository for descriptions of the processes, procedures, and treatments the patient received during their stay. From these ER charts, summary information is entered into the ER log. One month of summary data were collected from the ER log. The data collected were recent summaries for patients entering the Emergency Department from October 1 – October 31, 2003. The data included the following information:

- Date of entry
- Time the patient entered the ED
- Time the patient entered an ER bed
- Time the patient was discharged or admitted to the hospital
- The triage (acuity level)
- How the patient arrived – by EMS, a personally owned vehicle, or by law enforcement.
- Age
- Gender
- Hospital account number
- Name of the Treating Physician

- Who treated the patient – ER Dr., Personal Primary Dr., or both?
- Was the patient admitted to the Minor Emergency Care section of the ED?
- Was the patient released or admitted to the hospital?
- Was the patient transferred to another care giver?
- Did the patient expire?
- Did the patient leave without being seen (LWBS) or against medical advice (AMA)?
- Did the total length of stay (LOS) take more than six hours?

This data would allow researchers to calculate information used to measure three segments in a patients length of stay: the length of time it took for a patient to make it to an ER bed, the length of time it took from ER bed to discharge/admission, and the total length of stay. All the variables helped in generating inputs for the "as-is" base simulation computer model of the Emergency department. Especially important are the arrival rates and acuity levels of each patient.

In addition to the data gathered in the ER Log, two other sources of customer information were reviewed. The hospital employs the Gallup Organization to collect data on various aspects of the customers' perception of quality, efficiency, and adaptability. The historical records of this poll were used as the "voice of the customer". Since there is a long lag time between the service of a patient and the receipt of quarterly Gallup Poll results, the data from CTMC's internal customer satisfaction survey would be entered into an Excel format and imported into SPSS for data analysis.

The historical lab results for the month of October were used to determine the descriptive statistics regarding lab turn-around times (TAT). The hospital captures two different types of measurements regarding TATs – one is the time a lab specimen is received in the lab area until the time the results are reported back to the ER (receipt to result), the other is the time the order for a lab analysis is input into the ER computer system until the results are reported back to the ER (order to result). The order to result measurement is a better measurement of the overall TAT in regards to the patients' experience. The lab results were input into a Microsoft Excel spreadsheet and then imported into SPSS version 11.0 for analysis.

Direct Observations

The researchers conducted a one-month long observation of emergency department patients. The direct observations started on December 18, 2003 and were complete by January 18, 2003. A proportionally stratified random sampling plan was constructed in an effort to obtain a representative sample of the hospital's ED patients. The sample was stratified to include the proportionate amount of minor emergency and low acuity patients (which historically make up approximately 84% of the hospital's patients), and to follow these patients during a proportionate 3 hour time block during any given day. The observations were conveniently scheduled at two observations per day, except for Christmas day when only one observation was scheduled. The sampling plan was made available to observers via the internet. Each observer could sign-up for a specific observance listed on the sampling plan. The goal was to collect data regarding the time spent by patients in all phases of the process – from the time the patient enters the front door to the point they are discharged or admitted to the hospital. In contrast to the historical data collected for the ER Log, the direct observations were designed to collect finer detail. Many significantly unique sub processes were measured within each of the two major process measurements (Triage to ER bed, and ER Bed to Discharge/Admit) gathered by the ER Log. Also, the frequency and duration of the resources consumed by the patient – nurses, doctors, radiologist, respiratory therapists, laboratory technicians, and registration personnel - were captured.

The observers used a single, data collection spreadsheet and a stopwatch mounted on a clipboard. The researchers observed patients from the point of patient entry until exit. The observers simply noted the beginning and ending time, in minutes, that were displayed on the stopwatch. Also, the researchers simply noted or circled the appropriate attributes for a particular process – for example, whether the patient went for an x-ray, ultrasound, computed tomography, MRI, or nuclear medicine treatment. If special causes of variation were present, the observers simply noted that on the spreadsheet. The direct observations were tabulated and loaded into SPSS version 11.0 software for analysis.

CHAPTER 4

RESULTS

Six Sigma Results

Project Team membership and Identification of the VOC and VOB

The initial Six Sigma Project Team meeting held on October 17, 2003 yielded the following results:

- Financial measurements to be included in the Project Charter:
  - ➢ Revenue per ED patient.
  - ➢ Length of Stay (LOS)
- The identification of the "voice of the customer (VOC)" and the "voice of the business (VOB)":
  - ➢ VOC – the decision was to use the results of the Gallup Organization's telephone survey and the internal CTMC telephone survey to capture customers' satisfaction levels.
  - ➢ VOB – internal project leaders concluded that this would envelope two goals of the business – increasing quality care (especially in

- regards to reducing the number and sources of errors) and lowering patient admission times.

- Sub departmental sources for the internal project team members – at least one representative from each sub department would participate in all future Six Sigma Project Team improvement activities:
    - Laboratory
    - Radiology
    - Registration
    - Respiratory Therapy/Cardiology
    - Emergency Room Department
    - Materials

A review of the Gallup Organization's telephone survey of customers from Central Texas Medical Center provides the "voice of the customer (VOC)" in regards to satisfaction levels. The patient ranks their experience at the hospital on a four-point Likert scale: 4 = Very Satisfied, 3 = Satisfied, 2 = Somewhat Dissatisfied, 1 = Very Dissatisfied. Descriptive statistics are computed for each quarter and presented in the survey results. The historical records reviewed comprised four quarters worth of data spanning from Q3 2002 (July – September) through Q2 2003 (April – June). The survey focused on four major areas of measurement: Patient Loyalty, Overall Evaluation, People, and Speed and Efficiency. The four major areas of customer satisfaction measurements are subdivided into many subcategories. The lowest mean in each of the four quarters reviewed was "Wait Time" which is a subcategory of the major area labeled Speed and Efficiency.

The mean Wait Time scores in each of the four previous quarters were 2.73, 2.97, 2.90, and 2.95. Also, only 27 % of patients reported "Very Satisfied" scores in regards to Wait Time. When patients were asked where unsatisfactory delays occurred, 81 % of all the patients identified the delay before being taken to a treatment room. And, 56 % of all the patients identified the delay before being treated by a physician as unsatisfactory.

In addition, the major category of Speed and Efficiency showed a mean that was below the mean for all hospitals in the Gallup Healthcare Database. This data serve as a focal point for improvement efforts. The Gallup surveys suggest that a reduction in the mean waiting time and an improvement in the speed and efficiency of the operations would benefit the hospital, customers, and the community.

In addition to the Gallup Poll, the VOC as measured via the results of the CTMC internal telephone survey is shown in Table 3. The results comprise 491 surveys taken from September 1 through November 13, 2003. The mean scores of all ten questions show a high satisfaction rate, but reviews of the original survey forms show that this may be due to customers responding with the same score for all questions. Interestingly, the lowest mean score was for question nine – if delayed were you kept informed? The phrasing of this question implicitly means that the customer experienced a delay in care.

Table 3:

Results of CTMC Internal Telephone Satisfaction Survey

Subject of Question	Mean
Attentive ED staff	3.74
Responsive ED staff	3.76
Compassionate ED staff	3.76
Explanation of Meds & Procedures	3.74
Family informed of progress	3.75
Level of Privacy/confidentiality	3.80
Triage Nurse interview efficiency	3.78
Lab/X-ray efficiency	3.77
If delayed, were you informed	3.67
Discharge instructions adequate	3 77

Murphy's Analysis

A Murphy's Analysis was conducted to identify "defects" in the current CTMC Emergency Department processes. The 6 Ms technique was employed within the Murphy's Analysis – each defect was categorized into one of the 6 Ms:

- Man
- Machine
- Mother Nature
- Materials
- Method
- Measurement

SIPOC Map

On October 24, 2003 the Six Sigma Project Team met to develop the SIPOC map which details the basic processes, sub processes, inputs, and outputs of the ED business process. Figure A1 in Appendix A shows the results of the process mapping exercise. The project team summarized the basic processes as follows: the patient presents to Triage, they proceed to Registration, their care is managed and treated, and finally the patient is dispositioned. Thus, a more complex process is broken down into about 5 major processes which serve as the framework and focus for subsequent steps in the DMAIC methodology.

Cause & Effect Matrix

On November 11, 2003 a C & E matrix was constructed using the SIPOC map built in the previous stage. Table A1 in Appendix A shows the results of the C & E Matrix development. For each process input, the highest C&E scores were ranked to provide a paretoized list of problematic process inputs. Within these ranked process inputs, the "chart" input was identified twice – once in the registration process and once in the patient management process. Thus, a total of six process inputs became the focus for the FMEA portion of the DMAIC methodology. These process inputs were as follows: equipment and supplies, chart, diagnostic results (both lab and radiology), materials, personnel, and doctor communication.

Failure Modes and Effects Analysis (FMEA)

The FMEA was constructed over several Six Sigma Project Team meetings spanning from December, 2003 through March, 2004. The FMEA is a tool that uses as its inputs the Murphy's Analysis, SIPOC map, C & E matrix, and the current operating procedures. The output is a quantified list of defects. The defects with the largest RPN numbers become prime targets for improvement projects. Thus, the Project Team collectively determines the appropriate action items to address each defect – these projects and action items are the beginning of the Improvement phase within the Six Sigma DMAIC methodology. The FMEAs resulting from the Project Team meetings are shown in the Appendix A, tables A2 through A4.

Some members of the Project Team had the chance to visit other local hospitals in the area. The idea was to observe other "best practices" in the healthcare industry, specifically emergency department processes, in order to generate ideas for the team in the Improvement stage. These "best practice" observations were shared with the Project Team members before and during the Improvement stage. Some of the written observations of "best practices" are available for review in Appendix B.

Improvement and Control Phases

Through the use of the Six Sigma tool, this emergency department is making the changes in their processes that will help them grow to be a more efficient, effective, and adaptable organization. The hospital implemented a few significant changes in response to the excitement generated by the Six Sigma Project Teams presence. They have redesigned their Triage and Registration area. Before the redesign, many patients entering the emergency department were faced with two windows – one for Triage and one for Registration. So, many patients were incorrectly asking for medical assistance at the Registration window. The Triage window is the intended first stop for incoming customers. The hospital has walled off the window that faces the front entrance. This makes it a little more obvious to the patient that the first stop is at the Triage window. This decreases the amount of time wasted by the customer in traveling to and from the wrong area. Also, it eliminates some of the workload for the Registration personnel, as they no longer need to reroute new ED customers.

The hospitals' ED patients stated in the Gallup Poll that the waiting time, from their arrival to an ED bed, was the most dissatisfying portion of the total length of stay. Thus, a strategy employed by many emergency departments is to get the patient into a bed as quickly as possible. The Project Team decided to rework the front-end processes in order to reduce this time and to reduce the frequency of errors in the patient queuing process. Previously, the admission of patients into an ED bed was controlled by the ED personnel themselves. The difficulty with this was that there was not a single, independent person that controlled the flow of patients into an ED bed. By moving this decision process into the Triage area, the decision guided by a visual signal that an ED room was vacant (each room had a numbered clipboard that circulated back to the Triage area), the Triage personnel were empowered to move patients into an ED bed as soon as one was available. In addition, this new process reduced some transportation time as the registration personnel no longer needed to deliver a patient chart/clipboard to the ED; it was a much shorter distance to deliver these to the Triage room located right across the hall. And, the ED nurses did not have to walk all the way to the waiting room to "call" a patient back to the ED. This process was now controlled by the Triage nurse who had immediate access to the waiting room. This new process also benefited the MEC patients and personnel as the MEC nurse controlled the flow of their patients and the nurse did not have to travel as far to get the chart/clipboard from the ED in-rack. The MEC patient chart/clipboard was delivered directly to the MEC area by the registration personnel.

A pilot analysis of this new process showed that the improvements were effective. In early April, two days of non-EMS patients were analyzed and compared to the October ER Log historical data. The Independent t-test showed that there was a significant difference in the length of stay - from Triage entry to ER bed - between the October patients($M = 38.78$, $SD = 29.13$) and the April 2nd and 3rd patients ($M = 19.18$, $SD = 10.21$), $t(2186) = 7.31$, $p < 0.001$, two-tails. Notably, the new process reduced the variation in wait times. A review of the Levene's test for homogeneity of variance showed that the Levene's statistic was significant. Thus, the assumption of homoscedasticity could not be maintained. The data were reanalyzed using the Mann-Whitney U test since the Independent t-test was subject to scrutiny. The Mann-Whitney U test showed that there was a significant difference in the ranked lengths of stay - from Triage entry to ER bed - between the October patients ($n = 2069$, $\Sigma R = 2323024$) and the April 2nd and 3rd patients ($n = 119$, $\Sigma R = 71743$), $U = 64602$, $p < 0.001$. The limitation to the Mann-Whitney U test was that there were several tied scores used in the analysis. An analysis of the patients' total length of stay showed the same effect. The Independent t-test showed that there was a significant difference in the total length of stay between the October patients ($M = 137.87$, $SD = 81.78$) and the April 2nd and 3rd patients ($M = 107.14$, $SD = 68.21$), $t(2303) = 4.02$, $p < 0.001$, two-tails. Due to violations of the homoscedasticity assumptions, the Mann-Whitney U test was run and it showed that there was a significant difference in the ranked, total lengths of stay between the October patients ($n = 2069$, $\Sigma R = 2323024$) and the April 2nd and 3rd patients ($n = 119$, $\Sigma R = 71743$), $U = 64602$, $p < 0.001$. Thus, the variation in patient waiting time is being reduced dramatically. This leads to reductions in patient wait times and mean lengths of stay. An important effect of the reduced amount of waiting time on the front end of the process is that patients no longer have time to become dissatisfied with the service rate and leave the hospital. Thus, early data analysis shows that the patient "left without being seen" (LWBS) rate was decreased by 50%. At this rate, this new Triage to ED bed process prevents 16 patients per month from leaving the ED without being seen. This equates to an additional $97,089 in revenue per year considering that the average patient generates $505.67 per ED visit! As the project moves forward, additional data will be collected and analyzed to determine the efficacy of this process redesign.

In addition, the hospital is in the middle of restructuring their Triage room into two separate areas. They now have a Triage room that is dedicated to capturing the patients' chief complaint and their medical history. In the eyes of the patient they are getting immediate care. The second area is adjacent to the Triage room and is used for the sole purpose of capturing vital signs. From a process standpoint the physical location of this second room is advantageous in that it funnels exiting patients out in front of the Registration desk – the next step in the ED process. Also, the second room could be used as a second Triage room in cases of peak demand.

Another important improvement is to address the equipment, supplies, and materials problem as identified in the FMEA. Originally, there were three resupply rooms. One of these rooms has been eliminated to make space available for PACS equipment. The Material department and Emergency Department have agreed to create a cross-functional team to rework two resupply areas, and create a mobile supplies area nearer to the Trauma rooms within the Emergency Department. They plan to use the 5S technique (a Japanese term and technique that is used to optimizes the effectiveness of a particular workspace: Seiri - Sort/Discard, Seiton - Arrange/Order, Seiso Clean/Inspect, Seiketsu - Standardize/Improve, Shitsuke Believe/Discipline.Sort) to improve the layout of their two existing resupply closets. The process of installing the new shelving and mobile supply rack will result in the sorting, discarding, rearrangement, cleaning, and standardizing of these supplies areas. Once this is complete, control of the stock within this supply area will be managed by the Materials department instead of the Emergency Department. This improvement should result in reduced delays in patient service - throughout the treatment, management, and disposition processes - due to a more efficient and effective supply chain.

Eventually, once the improvements are in place, control charts will be used to maintain the gains generated from the project. Specific variables are chosen as input into an appropriate control chart. These variables are monitored by the ED personnel for "special causes" of variation that would indicate that the process is going out of control. As special causes of variation exhibit themselves, the control chart tools quickly highlight the existence of process problems, and thus make it much easier to identify the root cause of such problems. An additional advantage is that the control charts serve as a historical data set. This data provide a basis for continuous process improvement efforts.

Power Analysis

A Power Analysis was performed to determine an appropriate sample size for data collection. The analysis was performed using two different methods – hand calculation and via a software application. The hand calculated method used the Independent t-test formula shown below:

$$N = \frac{\left(\sigma_1^2 + \sigma_2^2\right)\left(z_{1-\frac{\alpha}{2}} + z_{1-B}\right)^2}{\Delta^2}$$

Pilot data from a 2-week collection of ER Log data were used to determine the mean and standard deviation for the initial hand calculations. The equation was used to generate values for the sample size "N" using different values for the effect size (Δ), alpha (α), beta (B), and the standard deviation of the two samples (σ_1 and σ_2). The hand calculated power analysis yielded the following results:

Using $\alpha = 0.05$, B = 0.20, and a 5% reduction in the LOS standard deviation and a 10% reduction in the mean LOS:

N = 533

Using $\alpha = 0.05$, B = 0.20, and a 5% reduction in the standard deviation and mean LOS:

N = 2114

A Power Analysis was also performed using the software application Sample Power version 1.20. Pilot data from the ER Log for the entire month of October 2003 were used to determine the mean and standard deviation for this analysis. The software assumes that the standard deviation remains constant for this analysis. This analysis yielded the following results:

Using $\alpha = 0.05$, and a 10% reduction in the mean LOS:

N = 540 with a resultant Power of 80%.

Using $\alpha = 0.05$, and a 5% reduction in the mean LOS:

N = 2140 with a resultant Power of 80%.

Through the use of several power analysis calculations it was decided that the sample size associated with an alpha level of 0.05, Beta of 0.20, and a 5% reduction in the mean would be appropriate for this study. Therefore, the sample size to be used to derive data – either historically from the CTMC ER Log or from direct observations – was determined to be approximately 2140 samples.

Historical ER Log Data

The ER Log data for the month of October 2003 were compiled into a Microsoft Excel spreadsheet. Since the ER Log time data were collected in military time, Excel functions were used to split the first two integers of the four digit military time - the hour of the day - and to capture the last two digits – the minutes of the day. The hour integers were converted to total minutes simply by multiplying by 60, and this result was added to the minute integers to yield the total minutes elapsed in the day for that particular point in time. The spreadsheet was imported into SPSS Version 11.0 statistical software package. The data were carefully reviewed for accuracy and completeness. The ER Log data yielded the following descriptive statistics for the different triage levels:

Table 4

Length of Stay from Triage to an ER bed

Triage Level	N	Mean	Standard Deviation
MEC	974	40.83	28.12
Low Acuity	881	41 90	29.88
Medium Acuity	228	26.71	27.34
High Acuity	6	51 33	57.53

Table 5

Length of Stay from the ER bed to patient Release

Triage Level	N	Mean	Standard Deviation
MEC	1010	60.05	43.77
Low Acuity	1093	135.32	87.17
Medium Acuity	368	174.28	90.21
High Acuity	12	133.92	64.55

The results of Table 5 show that the low and medium acuity patients are experiencing the highest variance in the ED process. Since the MEC and Low acuity groups comprise approximately 84% of all patients, improvements within the entire ED process should impact these two groups.

Table 6

Total Length of Stay (LOS) Descriptive Statistics

Triage Level	N	Mean	Standard Deviation
Per Triage Level			
MEC	1029	98.53	50 99
Low Acuity	1126	168.05	88 02
Medium Acuity	379	189.55	90.05
High Acuity	12	159.58	60 59
Totals - All Triage levels combined			
	2546	143 64	84.54

Once again, the overall descriptive statistics in Table 6 show that the two groups with the highest LOS variability are the low and medium triage level groups. All of the patients in these two groups are serviced in the non-MEC emergency rooms. And, most are serviced by personnel and processes that are shared between all the triage groups. In contrast, it was thought that the MEC patients benefit from the focused nature of the service rendered during the MEC clinic's hours of operations. These patients are afforded care in dedicated rooms and from dedicated resources – an MEC Physicians Assistant, or Nurse Practioner, and an MEC Nurse. Similarly, the high triage level patients are likely to be serviced quickly by dedicated personnel in specialized trauma rooms. Thus, they are likely to experience more efficient care simply due to the severe nature of their acute health condition.

The ER Log data were analyzed to understand how patients enter and exit the ED process. Table 7 shows that over two-thirds of ED patients are ambulatory arrivals

(POV A). These patients enter the front entrance of the ED facility and flow normally through the process as identified in the SIPOC map.

Table 7

Patient Type of Arrival Frequency Table

Type of Arrival	N	Percentage
EMS	404	15.3
POV A	1770	67.2
POV W/C	148	5.6
POV P	312	11.8
HCSD	1	< 0.001
SMPD	0	0
Totals	2635	100%

The EMS patients make up only about 15% of all patients. Since the number of these types of arrivals is relatively small, the hospital accommodates its normal processes to these arrivals. The EMS patients typically arrive via an ambulance, thus in the beginning stages of the process, they are processed in a slightly different manner than ambulatory patients. They require the immediate attention and reaction of personnel in preparing for arrival. In many instances, the EMS patient draws resources away from their normal areas/modes of operation. For example, since the EMS patients arrive in back of the ED area, the registration personnel must leave their office space in the front of the ED area and travel to the appropriate trauma room to get the patient information that is necessary to register the patient. These sub processes were important considerations in the development of process improvements. Some improvements may have a direct impact on a minority of patients, but in an indirect manner, the improved process may affect all patients.

Patients were dispositioned from the ED in one of four ways: release, admitted to the hospital, sent to the operating room, or transferred to another hospital. In addition, there were also other special situations – for example, the patient may have expired, a special hospital code may have been called which would require special resources (cardiac arrest or life threatening), a patient could leave without being seen (LWBS), a patient left against medical advice (AMA), and/or the patient's total length of stay was greater than 6 hours. Table 8 displays the descriptive statistics for patient dispositions.

Table 8

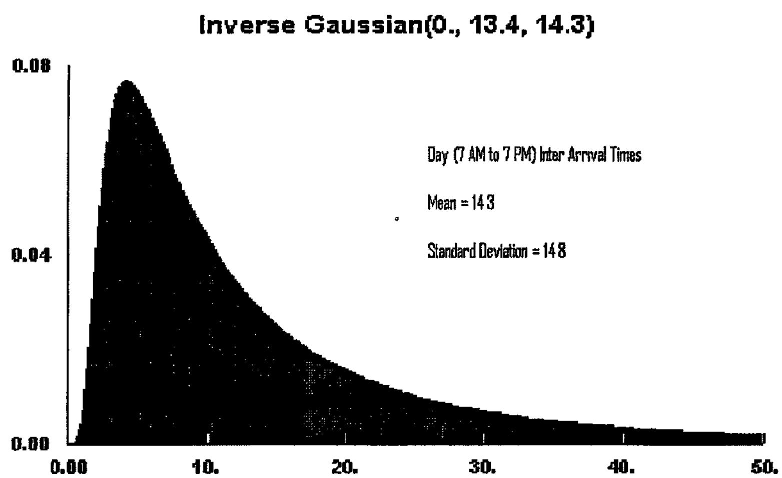
Patient Disposition and Special Situations

Disposition	N	Percentage
Released	2316	87.7
Admitted	255	9.7
Op Room	20	0.8
Transfer	9	0.3
Expire	3	0.1
Code	2	0.1
LWBS	32	1.2
AMA	2	0.1
Totals:	2639	100%

The inter-arrival time, a measurement of the difference in time between consecutive patients arriving at the hospital, is shown for the day shift in Figure 3. The raw data were captured in an Excel spreadsheet and moved to a text file (Notepad). It should be noted that the accuracy of the inter-arrival time calculation requires that the time a patient arrived at Triage is captured accurately for every patient. There were four missing data points in the ER Log. To remedy missing data, the midpoint between the previous and subsequent patient arrival time was used for the missing arrival time. The completed text file was then imported into the StatFit module within MedModel. The "best fitting" distribution for this data was the Inverse Gaussian distribution.

Figure 3

Day shift Inter-Arrival Times Distribution



The difficulty in using only one inter-arrival distribution for a non-terminating simulation is that it does not take into account for changes in inter-arrival times due to the time of day. For example, the Emergency Department is busier during the hours of 9 AM – 11 PM, and not as busy in the early morning hours. It was thought that this could be solved by producing two separate inter-arrival distributions – one for the daytime hours and one for the nighttime hours – but it was not evident that MedModel could be programmed to accept two separate inter-arrival distributions, much less several 3 hour time blocks of inter-arrival distributions. An alternate solution to this problem was used which involved determining the arrival statistics and distribution of EMS and non-EMS patients. Table 9 shows the descriptive statistics for the two entry points to the emergency department.

Table 9

Patient Arrivals – EMS versus Non-EMS

Arrivals	Mean	Standard Deviation
Non-EMS	72.16	11.18
EMS	13.03	4 62

Next, the distribution of triage type was determined for both the EMS and non-EMS patients. Table 10 shows the distribution of triage types within the EMS and non-EMS arrivals.

Table 10

Arrivals - Triage Type Distribution

Triage Type	% of TI Patients
Non-EMS Patient Type Distribution	
MEC	47
Low (Brown)	42
Medium (Yellow)	11
High (Red)	0
EMS Patient Type Distribution	
MEC	0
Low (Brown)	59
Medium (Yellow)	38
High (Red)	3

Finally, the ER Log was used to analyze the distribution of arrivals per 3-hour time block during the day. This was done for both the EMS and non-EMS patients. Table 11 shows the results of this analysis.

Table 11

Arrivals – 3-Hour Time Block and Entry Point Distribution

	EMS Arrivals	Non - EMS Arrivals
Hour Block	% of TI Arrivals	
0 - 3 AM	10.4	6 3
3 - 6 AM	7.4	3.8
6 - 9 AM	7.9	8 7
9 - 12 AM	13.1	14.8
12 - 3 PM	15.8	15.9
3 - 6 PM	13.9	17.7
6 - 9 PM	18.4	19.9
9 - 12 PM	13.1	12.9

Thus, using the descriptive statistics and distributions of patients, an arrival cycle was generated that best simulates the changes in workload at various times during the work day and the changes in patient types arriving at two different locations in the emergency department.

Direct Observations

One of the constraints of taking direct observations in a healthcare application is that the time required to make one complete observation can be extensive. For this reason the amount of samples gathered were small, and the validity of such a small sample size limits this study. To assess the validity of the direct observation data, the results for the 59 MEC/Low Triage level samples collected via direct observations were compared to the 2155 samples gathered from the ER Log. The comparison of the overall LOS descriptive statistics show a moderate fit between the ER Log and Direct Observation data. The difference in LOS between the two groups of data were not statistically significant, $t(2212) = -1.856$, $p > 0.05$, two-tails. This comparison is shown in Table 12.

Table 12

Comparison – ER Log versus Direct Observation

MEC and Low Triage Acuity Patients	Mean	SD	Mean	SD
	October ER Log		Direct Observations	
Total LOS	134.86	80.58	154.68	93.22

Note: Difference is not significant, p > 0.05

The data gathered via direct observations were critical in the formation of the "as-is" computer simulation model. In addition, the notations regarding special causes of variation were helpful in the supporting the findings in the Six Sigma methodologies. A simple scattergram of the cases versus the length of time a patient spent being processed in any one of the process steps provided the researcher with an interesting exploratory tool. The cases that were subjected to extraordinarily long lengths of stay are easily identified on the scattergram. And, by concurrently comparing this scattergram with a simple boxplot, the high extreme and outlier cases are positively identified on the scattergram. This then allowed the researchers to go back to the original data collection sheets and classify the variation in the extreme and outlier cases as due to either common or special causes of variation. It should be stressed here that there are those cases that may exhibit long lengths of stay, but are due to common causes of variation. And, in certain cases extended lengths of stay may be the normal byproduct of medically prudent processes. These are not the cases we are focusing upon. The special causes of variation are the focus of Six Sigma improvement efforts. Therefore, simple statistical analyses of the direct observation data were valuable in identifying special causes of variation and in validating the direction of Six Sigma improvement efforts.

Other Historical Data

Lab Results

The origin of the data, for both the historical and direct observations, was from the hospital computer records. Since the historical data gathered from the hospital's electronic records for the month of October was a much larger sample than the sample gathered from the direct observations, the historical results were used to determine the descriptive statistics regarding lab turn-around times (TAT). Table 13 displays the overall descriptive statistics for the Order to Result Lab TAT.

Table 13

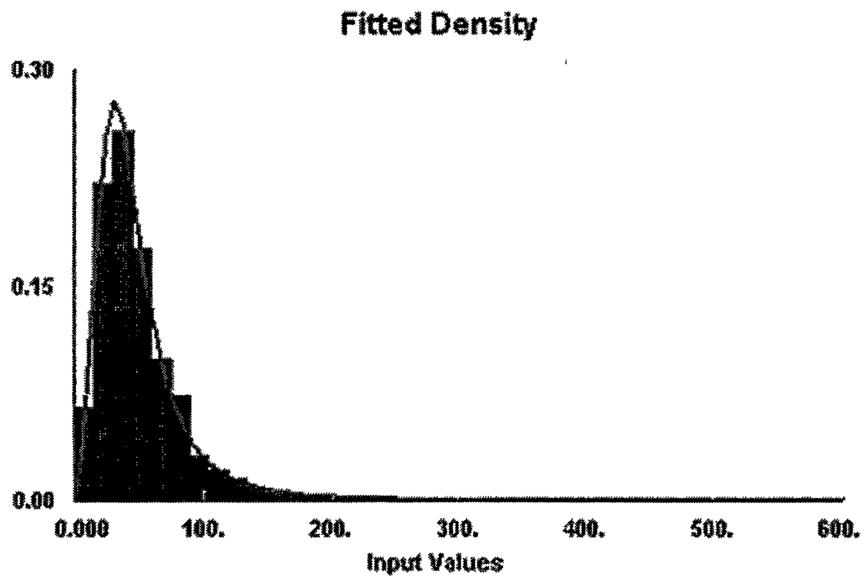
Lab TAT – Order to Result

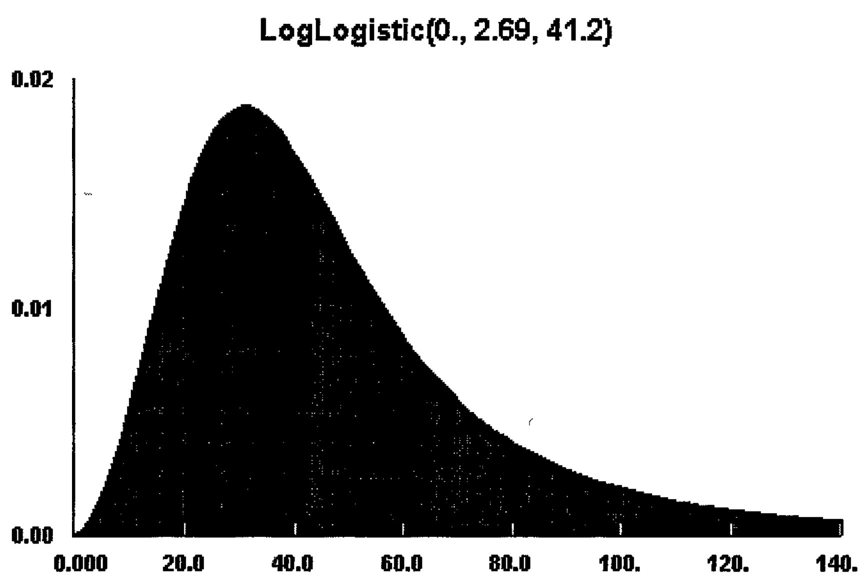
Lab TAT	N	Mean	Standard Deviation
Order to Result	2257	50.80	40.29

The raw data were then imported into MedModel's StatFit program, via a text file, in order to assess the distribution of the data. Figure 4 displays the histogram and "best-fit" distribution for these data.

Figure 4

Lab TAT – Histogram and Best Fit Distribution





Statistically, the "fit" of the Log-Logistic distribution was significant as measured by the Kolmogorov-Smirnov test, $p > 0.05$. The Normal distribution was not a significant fit for the data, thus the Log-Logistic distribution was used to simulate the Lab TAT for each patient in the computer simulation.

Radiology Results

The hospital's electronic records for ED radiological procedures for the month of October were analyzed and are shown in Table 14.

Table 14

Radiology TAT

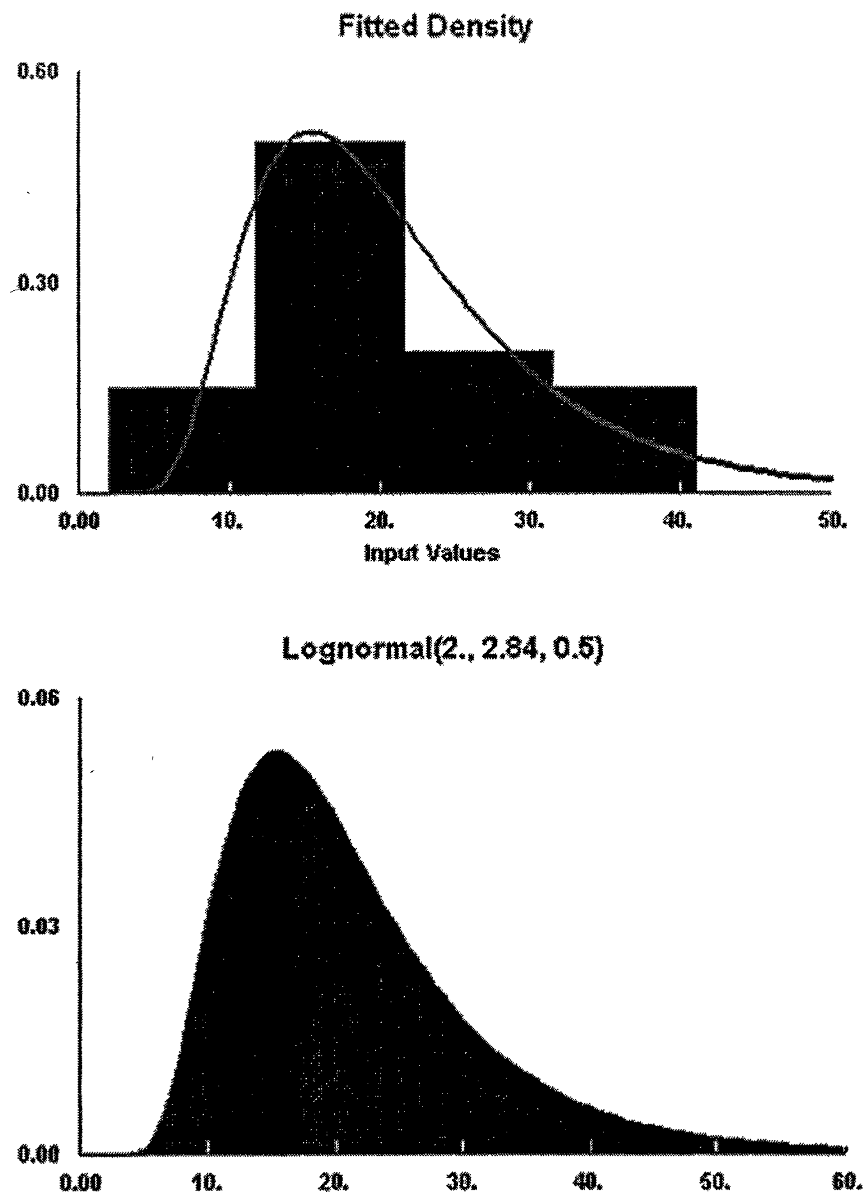
Radiological Procedure	N	Mean Time per procedure (minutes)
X - Ray	1277	30
CT - Computed Tomography	215	44.7
US - UltraSound	122	60
MRI - Mechanical Resonance I	3	50
NM - Nuclear Medicine	0	0

Note: NM is usually < 1 % of total radiological procedures.

The hospital's frequency data for the month of October were used to validate the correct distribution of each procedure in the computer simulation. Unfortunately, the report did not detail the actual TAT for each radiological procedure; the report only summarized the total minutes and quantities for each procedure. Thus, the variance for each technique could not be computed. For purposes of building a valid computer simulation model, the mean and standard deviation for twenty x-ray procedures were computed from the direct observations. The mean and standard deviation resulting from this sample were 20.1 and 14.6 minutes respectively. However, there was reason to believe that the Normal distribution would not be a good choice to simulate the x-ray TATs. Again, StatFit software was used to determine the "best fit" for the data. Figure 5 displays the histogram and fitted distribution.

Figure 5

Radiology X-Ray TAT – Histogram and Best Fit Distribution



The Lognormal fit was significant using both the Kolmogorov-Smirnov and Anderson-Darling tests, both $p > 0.05$. Thus, this distribution was used in the computer simulation for the x-ray TATs instead of the descriptive statistics from a Normal distribution. For each of the less common radiological procedures - CT, US, MRI, and NM - interviews with the supervisor of the radiological department resulted in the formulation of triangular distributions.

Computer Simulation

AutoCad Background

An AutoCad drawing of the hospital's floor plan was obtained from the hospital's director. This drawing was then manipulated using AutoCad 2002 software in order to remove any extra detail that wouldn't be needed in the MedModel simulation. Drawing notes, extra symbols, and doors were removed to obtain a simple representation of the emergency department layout. This drawing was cropped, then cut and pasted into Microsoft Paint software as a bitmap. This bitmap rendition of the hospital's floorplan was imported into the MedModel software. To correctly scale the floor plan, a direct measurement of one of the longest hallways in the emergency department was taken. This measurement is then used to compute the length of one "grid" in the MedModel computer model.

Computer Simulation Program

Once the background was imported into MedModel, the remainder of the simulation program was built, in stages, using the data from three different data sources: the historical data from the ER Log and other electronic records, direct observations, and interviews with the hospital staff. The process of building the model involved progressive refinements of simple programs. The complexity of the model was increased as each refinement was implemented. Also, after each refinement, the program was run and observed to verify that the program was working correctly. The validity of the model was checked by gathering output from the model and comparing the output to the historical or direct observation data. The model was also presented to project team members and hospital staff for validation. The computer program for the "as-is" simulation is shown in Appendix C. The inputs for the simulation are shown in Appendix D.

Warm-up Period

Once the final "as-is" model was verified and validated, the model was run to determine the warm-up period. This is the period it takes for a non-terminating model to reach a steady state of operation from the start-up of the model. An arbitrary warm-up period was entered into the program's start-up features; the model was run for 7 replications of 30 days each. The number of patients in the emergency department, at 12 P.M., was logged for each of the 30 days in each of the 7 replications. Then, the mean number of patients in the system was calculated for each day. This results in 30 daily averages. These averages are then used to generate several different moving average scenarios. The moving averages for 2, 5, 7, and 10 days were calculated and line-graphed. The line graphs were examined for smoothness; the smoothness of the graphed line is the indicator of a "saturated" model. The graphed, moving averages exhibited smoothness somewhere between the 5th and 7th day of operation. Thus, the model was programmed to use a warm-up period of 7 days. The MedModel software used the 7-day warm-up period for each repetition, or "run", of the model.

Run Length and Replications

The "as-is" model was run for 24 repetitions of 30 days each. MedModel uses a different random number seed to start each repetition. Thus, each repetition simulates an independent, 30-day sample of hospital patients. So, effectively an entire simulated run gathered 2 years worth of patient visits. The 24 samples were used as the baseline dataset for comparison purposes. The "what-if" models were built, validated, and verified using the base, "as-is" model. Each "what-if" model, or scenario, was run for 24 replications of 30 days each. Finally, each set of 24 "what-if" replications was statistically compared to the results of the "as-is" data.

Scenario 1 – The provision of additional operating hours for the MEC area

Scenario 1 was used to check the effect of the addition of MEC hours upon patients' LOS. The "as-is" model consisted of MEC hours spanning from 11 A.M. to 11 P.M., 12 hours of operation. The "what-if" model consisted of MEC hours spanning from 9 A.M. until 2 A.M. the next day, effectively 17 hours of operation per day. A statistical analysis using the Independent t-test showed that there was a significant difference in the average LOS for all patients between the 12 hour ($M = 142.81$, $SD = 3.39$) and 17 hour ($M = 138.12$, $SD = 2.70$) MEC operational groupings, $t(46) = 5.29$, $p < 0.001$, two-tails. Overall, the addition of hours in the MEC area resulted in a 3.3% decrease in the overall, mean patient LOS. Separate analyses of each triage level (MEC, low, medium, high) revealed a decrease in the mean LOS for each patient type, however only the MEC and low triage level patients experienced significantly decreased lengths of stay - both significant at $p < 0.001$.

Scenario 2 – The addition of a Hematology Technician

In scenario 2, a Hematology Technician was added to the computer simulation. This technician's sole responsibility was to draw and deliver patient's lab samples. The perceived advantage of this additional resource is that it would allow either the Nurse or the Nurse Technician to perform other tasks. The additional advantages, which could not be tested in this scenario, was that the use of a specialized technician dedicated to performing blood draws would substantially reduce the number of "missed" or "defective" blood draws. The Independent t-test showed that the overall LOS of patients for patients in the "as-is" model ($M = 142.81$, $SD = 3.39$) was not significantly different from the LOS with the hematology technician ($M = 143.13$, $SD = 2.65$), $t(46) = -0.367$, $p > 0.05$, two-tails. This scenario did not measure the effect of some other advantages to having this resource working in the ED. For example, it is theorized that the number of "bad or missed" blood draws would decrease. And, a specialized technician who is sensitized to the importance of the quick delivery of samples to the lab would decrease hemolyzation rates.

Unsurprisingly, the analysis did show a significant decrease in the Nurse utilization rate. The addition of a hematology technician resulted in a 10.3% decrease in Nurse utilization.

Scenario 3 – The addition of PACS technology

In scenario 3, the effect of the addition of a PACS system on patients' LOS and the Radiology Technician utilization rate was simulated. The PACS system was in the process of being installed during this project and the hospital management wanted to assess the impact upon their patients. The PACS system would eliminate the need for the Radiology Technician to deliver x-ray film from the x-ray room to a review room. And, it eliminates the need for a Radiology Technician to transport the x-ray film from the review room to the x-ray results rack on the ED desk. Through the use of this technology the time to electronically transfer digitized x-ray images, from the x-ray room to the PACS monitor located behind the ED desk, would be less than a second. Therefore, it would be possible for the ED Doctor to view an x-ray result before the patient was wheeled back to their room. In addition, the Radiology Technician is freed to perform other duties. A statistical analysis using the Independent t-test showed that patients' "as-is" length of stay ($M = 142.81$, $SD = 3.39$) was significantly reduced by the addition of the PACS technology ($M = 137.39$, $SD = 2.55$), $t(46) = 6.248$, $p < 0.001$, two-tails. This resulted in a 3.8 % decrease in the overall, mean LOS. Further analysis showed that the addition of the PACS technology resulted in a significant decrease in the mean LOS for the 3 lowest Triage acuity level patients, $p < 0.001$. The technology did not impact the LOS for the highest acuity level patients.

In addition, an analysis of utilization rates show that the "as-is" model rates ($M = 41.17$, $SD = 1.42$) was significantly reduced by the addition of the PACS technology ($M = 38.71$, $SD = 0.96$), $t(46) = 7.02$, $p < 0.001$, two-tails. Thus, Radiation Technicians benefit from a 2.5 % mean decrease in the utilization rate. This reduction is realized for the work done for ED patients only and does not include any additional gains that might me realized for the work done upon non-ED patients.

Scenario 4 – Bedside Registration and addition of a Discharge process

Scenario 4 evaluated the effect of a change in the registration sub process coupled with the addition of a new discharge process. The current registration process occurs just after the patient is triaged and before the patient is actually called back into an ED room. The change in this process moves this work content from the front end of the entire process to the back end. Under the new process the patient would be registered in an ED room at their bedside. Theoretically, the patient could be registered during an idle time in the ED room – possibly while waiting for lab results to be returned. In this simulation if the patient received lab work the Registration Technician would perform the registration task while the patient and staff were idle, otherwise the registration of the patient was processed after initial care was completed. In addition, the hospital wished to simulate the addition of a discharge process in which the patient would be required to arrange for payment of the services rendered. This new process was added as the last process each patient would go through before exiting the hospital. A statistical analysis using the Independent t-test showed that patients' "as-is" length of stay (M = 142.81, SD = 3.39) was significantly increased by the addition of the new bedside registration and discharge processes (M = 147.80, SD = 2.53), $t(46) = -5.779$, $p < 0.001$, two-tails. This equates to a 3.5 % increase in the overall, mean LOS. Inspection of each of the four different triage groups showed that the LOS significantly increased for each group except for the highest triage group. The fact that the highest triage group was not significantly affected makes sense since these patients usually require a Registration Technician to travel to them anyway. In most cases these patients arrive by EMS, they are non-ambulatory, and are immediately taken to a triage room. Interestingly, the "as-is" utilization rate (M = 32.59, SD = 0.76) of the Registration Technicians was significantly reduced by the new process ($M = 31.92$, $SD = 0.82$), $t(46) = 2.92$, $p < 0.01$, two-tails. This was surprising since the same "as-is" distribution of task time for the registration process was used in the scenario. The decrease may be due to a reduction in the time the technicians spent traveling back and forth from the triage rooms, which were the farthest from the registration office area compared to the other ED room, to the registration office.

CHAPTER 5

CONCLUSION

This study was successful in that it combined the use of two engineering tools – Six Sigma and Computer Simulation, to improve a healthcare operation. In the hands of a professional healthcare engineer the tools are likely to be used for specific purposes. The Six Sigma tool is a great choice to approach process problems of varying complexity. The Computer Simulation tool is most valuable when proposed Six Sigma improvements have high risk levels associated with their implementation.

Most organizations use the Six Sigma methodologies as a business strategy. In this context process improvements do not end, they are continually improved. Although the Emergency Department of CTMC is just beginning to measure their process improvements the early results show that the tool is effective. The new Triage process is moving patients into emergency beds more effectively and efficiently. The variation in patient wait time is reduced and the mean LOS is shifting in the correct direction – downward. This reduction in waiting time helps to reduce the number of patients leaving the hospital without being seen and may generate an additional $97,089 in revenue per year. As the length of stay decreases, the customer satisfaction levels as measured by the

Gallup Poll should increase. And, ultimately employee satisfaction should increase as they work in an efficient, effective, less-stressful environment.

The computer simulation scenarios were natural extensions of the Six Sigma methodologies. As the team members worked through the C & E Matrix and the FMEA it became clear that there existed potential solutions that would be too difficult to try experimentally. The advantage to this tool is that these solutions can be experimentally simulated at no or little cost. The data yielded from the computer simulations were helpful in determining the impact of adding MEC hours, a Hematology Technician, a new bedside registration and disposition process, and new information technology in the form of a PACS system. Although the hospital did not believe any of the scenarios were of immediate value, some of the results are useful in light of their planned information technology implementations. As new technology is transitioned into the ED there will be processes that will need to be redesigned. Both the Six Sigma and Computer Simulation tools should be used to help smooth the transition and maintain customer satisfaction levels through the early implementation period.

Customer satisfaction is certainly important to the ED, but what is often overlooked is the satisfaction level of the employees themselves. There is a noticeable appreciation of the value of quantitative measurement amongst the Project Team members. They genuinely seem excited about measuring their processes and progress. Managers from different departments are working together to measure and solve process problems. Together they are weeding out the “special causes” of variation, regardless of who they believe might be at fault. One of the benefits of Six Sigma is that it can change an organization's culture. Data transparency is the key to breaking down organizational silos and it helps teams to focus on solving process problems; not people problems.

One of the difficulties experienced during this study is developing an ability to calculate cost savings or increased revenue. In the service environment, it is difficult to tie cost savings directly to decreased patient LOS. If the Six Sigma methodologies were to decrease patient LOS by 5%, and we could fill this 5% void with additional patients, then based on the yearly revenue figures for the Emergency Department this would equate to $450,328 in additional revenue. And likewise, it is difficult to tie increased revenue to an increase in patient satisfaction. In a recently circulated e-mail, an attendee of the 2004 Six Sigma for Health Care Conference noted that there was a study that was completed by the Sears, Roebuck and Company that showed a 0.80 correlation between employee and patient satisfaction. The inference was that a 1.3% increase in patient satisfaction would generate a 0.5% increase in revenue. If this relationship was accurate, and the ED improvements generated a 1.3% increase in the Gallup Poll customer satisfaction level, this would equate to $45,033 in additional revenue. Hopefully, healthcare organizations will embrace the Six Sigma culture and realize these potential gains.

Each hospital emergency department has its own, unique business environment and operational constraints. A non-punishing, data-oriented, process-focused, business approach to solving process problems is the key towards making steady organizational improvements. One of the key ideas of the previous statement is that process improvements should first focus upon the suboptimal processes that are the root cause of problems and not upon the people themselves. Mistakes will occur regardless of the quality of the people involved in the process or how well trained they are in conducting their work. If engineers can focus on developing mistake-proof processes, we can begin to reach the goals of Six Sigma – 3.4 defects or "mistakes" per one million opportunities. It can be done; other industries have a proven track record of this level of success. Through the wise application of quantitative measurement skills and proven, process improvement tools the healthcare industry can make great leaps towards world-class quality levels. A stronger, more effective, efficient, and adaptable healthcare industry will ultimately make our communities and our nation stronger.

APPENDIX A

Figure A1

SIPOC Level 1 Process Map

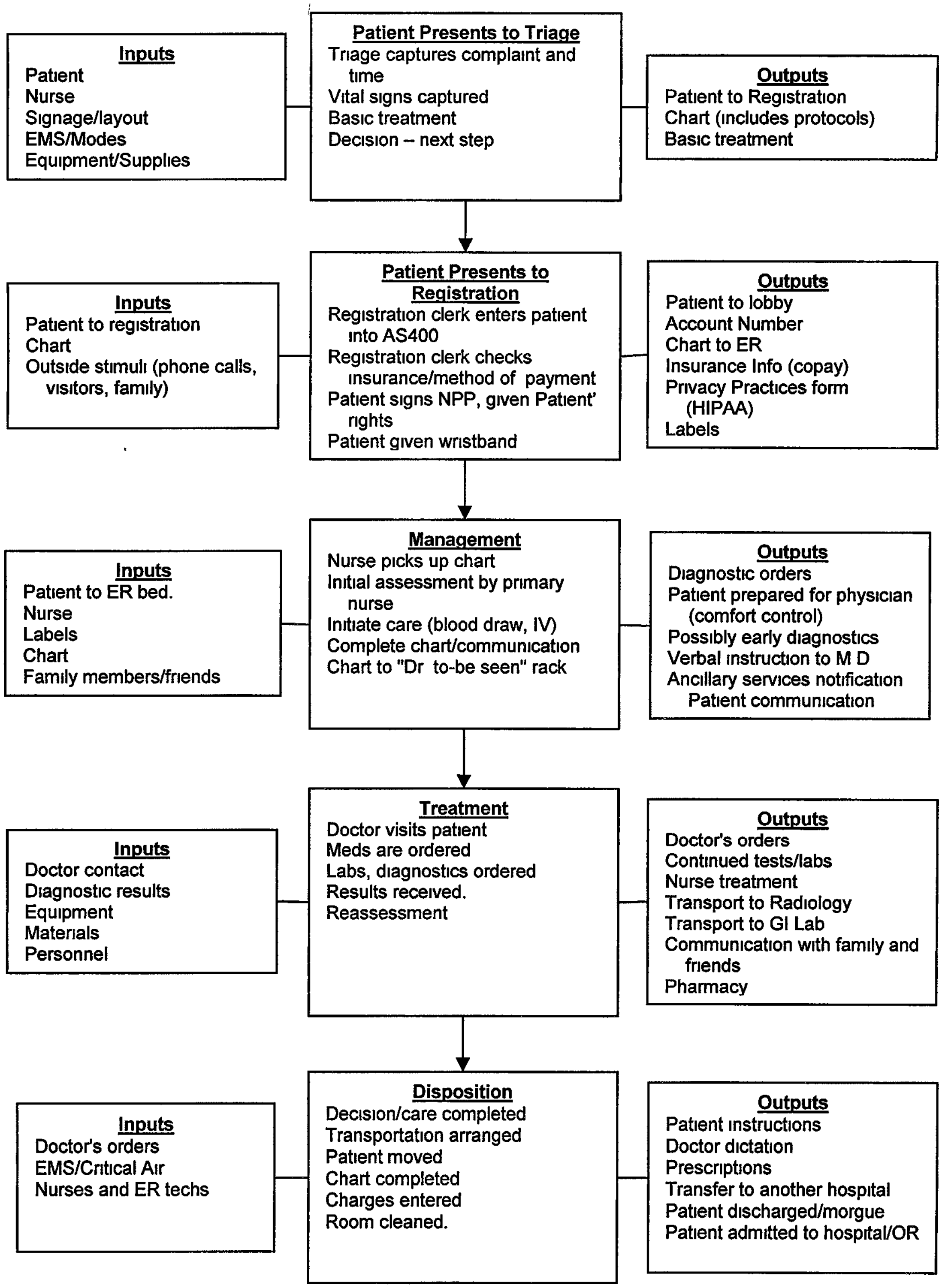


Table A1

C & E Matrix

Process Input	Quality Care	Error Reduction	Speed of Service	Total Score	Ranked Total Scores
Ratings of Importance to Customer	10	6	8		
Patient Presents to Triage					
Patient	3	0	9	102	-
Nurse	9	3	1	116	-
Signage/Layout	3	1	9	108	-
EMS - Modes of Entry	0	0	3	24	-
Equipment and Supplies	9	9	9	216	1st priority
Patient Presents to Registration					
Patient	0	9	3	78	-
Chart	9	9	9	216	1st priority
Outside Stimuli	9	0	3	114	-
Management					
Patient to ER Bed	1	1	9	88	-
Nurse	3	1	9	108	-
Labels	3	9	3	108	-
Chart	3	3	9	120	3rd priority
Family and Friends	3	0	9	102	-
Treatment					
Doctor Contact	3	0	9	102	-
Diagnostic Results	9	9	9	216	1st priority
Equipment	3	3	3	72	-
Materials	9	9	9	216	1st priority
Personnel	9	3	9	180	2nd priority
Code Teams	1	1	3	40	-
Disposition					
Doctor's Orders	3	1	9	108	-
EMS/Critical Air	3	1	9	108	-
Nurses/ER Tech	3	1	9	108	-
Doctor Communication	9	1	3	120	3rd priority

Table A2

FMEA Results – Chart, Personnel, Doctor Communication

Process Step/Part Number	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN
Chart								
	Patient's chart is missing	Personnel misplaces chart	10	Inefficient chart system.	8	No control.	10	800
	Chart not moved from registration to ER.	Patient experiences unnecessary wait time	10	Registration lets charts sit in office due to low manpower	7	No control	8	560
	Charts arrive to ER in no particular order	Some patients waiting in ER longer than others	9	Times are not used by ER staff when calling patients back into ER	7	No control.	9	567
	Doctor unsure of the order that patients need to be seen	Some patients waiting in ER longer than others	9	Doctors have no visual indicator	7		8	504
	Order entry errors from chart	ER Tech has pile of charts on desk in front of him, doesn't have a way of organizing them for priority	7	Inaccurate or delayed orders for patients in the ER	9	No control	9	567
Personnel								
	ER Tech answering unneeded phone calls	ER Tech is taken from more pressing tasks	7	Calls are allowed to go directly to the ER	9	No control	8	504
	Unable to track where personnel are at any given moment. Appropriate personnel needed for urgent issues (i e EMS patients)	Wasted time finding personnel for questions	7	No indicator of where personnel is	8	No control	8	448
Doctor Communication								
	Doctor unavailable	Delay in care	6	Misc - Doctor in patient room ,breakroom, or elsewhere	4	No control	3	72
	No patient disposition	Delay in care, delay in dipositioning patient	4	General oversight - not written on chart	3	No control	3	36
	Missing medication indication on chart	Delay in care, delay in dipositioning patient	4	General oversight - not written on chart	2	No control	2	16
	Missing written diagnosis on chart	Delay in disposition	4	General oversight - not written on chart	3	No control	3	36

Table A3

FMEA Results – Materials, Equipment and Supplies

Process Step/Part Number	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN
Materials, Equipment and Supplies								
	Cannot find mobile pc equipment I e IV pump)	Delay in service.	10	Did not clean after use	5	No control	9	450
			10	Has not been returned after a transfer from other floors	5	Order from sterile supply	8	400
	Supply shortages	Delay in service	10	Unorganized reordering process	10	No control	5	500
	Technical terms only on order forms	Wrong items ordered	10	Terminology unclear to some of the ER staff	8	No control	5	400
	Unorganized inventory process	Delay in supply delivery	10	Night techs ordering, then leave for a m for delivery to materials	8	No control	5	400
			10	Materials misplaces the order.	3	Material dept downloads the reorder sheets	1	30
			10	Speed of receiving supplies	1	Currently have a 24-hour turnaround on receiving	1	10
	Slow turnaround time on equipment installation	Delay in equipment usage	8	Personenl shortage	8	No control	5	320
	Slow turnaround time on basic ER maintenance	Items remain broken, laying around, causing delays.	8	Lack of understanding of urgency	8	No control.	5	320

Table A4

FMEA Results – Diagnostics (Lab and Radiology)

Process Step/Part Number	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN
Lab								
	Wrong labels on the specimen	Delay in process	10	Registration mislabeling on the chart	3	Registration Mgr meets with staff if problems arise	8	240
		Quality suffers	10	ER mislabels the specimens	3	Safety checks learned in nursing school	10	300
	No label on the specimen	Delay in process	10	ER rushing/busy	3	Safety checks learned in nursing school	10	300
	Test not ordered in computer	Delay in process	9	ER Tech rushing or too busy	3	No control	10	270
			10	Miscommunication	4	No control	10	400
	Lab collects specimens	Delay in process	4	Lack of experienced phlebotimist.	4	No control, lab must witness or draw blood on type screens?	10	160
	Delay in delivery	Delay in process	9	ER miscommunication	4	No control	10	360
	Equipment Malfunction	Delay in process.	10	Inclement weather	3	Preventative maintenance	10	300
	Hemolized Specimen/short sample	Delay in process	9	Lack of experienced phlebotimist	5	No control, ER can tell who's in the lab by the speed of sample	10	450
	Slow lab techs	Delay in process	10	Lack of abilities	8	Helping and coaching	1	80
	Large work load.	Delay in process	8	Large events/accidents.	3	Lab staffing is increased	7	168
Radiology								
	On call CT Tech	Delay in process.	10	Personnel issues-CT Tech not answering pager	3	No control.	10	300
	Telerad Failure	Delay in process.	10	Old Apple product, only 1 person that can work on it	1	No control	10	100
	Communication failures-lack of system	Delay in process	10	Communication breakdown	8	No control.	10	800
	Delay in reading.	Delay in process	10	Radiologist not around	5	Call into radiology by ER tech	8	400
			10	Radiologist not on staff.	5	Call into radiology-delays usually don't happen after call	7	350

APPENDIX B

Observations of "Best Practices"

In preparation for the "improvement" phase of the DMAIC Six Sigma methodology several members of the Project Team visited other hospital's Emergency Departments (ED) in an effort to understand what business processes they were using to control patient flow. On November 25^{th,} 2003 we visited the ED at McKenna hospital in New Braunfels, Texas and Brooke Army Medical Center in San Antonio, Texas. At each facility the team met with representatives from the hospital and was given the opportunity to tour the ED, make general observations, and to ask questions regarding their business processes.

McKenna Hospital - New Braunfels, Texas

Upon entry of the waiting room it is obvious to patients entering the room that the first stop for the patient is the Triage window. At the Triage window the patients are asked to fill out their name, SS number, and date of birth on a small slip of paper. It is possible at this point that the patient could be called into Triage immediately. The Registration clerks periodically walk across the hallway, pick up the slips of paper, return to the Registration windows, and enter the patients information into the hospital's computer. The hospital collects only a minimum of patient information on the front end of the process in an effort to reduce wait time. The representative referred to the process as a "mini-registration". Once a "mini-registration" is done the chart is placed in a wire rack just outside the registration door and visible to the ED personnel. A complete registration of the patient is done bedside – the hospital has mobile computers on rolling racks that can be rolled to the patient's location. In addition, insurance/payment processes are completed after the patient has received their treatment. Interestingly, this process was developed by the hospital's internal Process Improvement team with a goal of reducing the initial waiting time of patients on the front end of the treatment process. By streamlining the process - by moving paper work from the front end to the back end of the process - a patient gets into an ER bed as quickly as possible, and they get treated by a physician sooner. The goal is for a patient to see a physician within 10 to 12 minutes. An increase in patient satisfaction is the desired result.

The actual patient chart used included check boxes that clearly identified the patient's acuity level. The layout seemed to be simple and easy to use.

The hospital also utilized a chart and clip system. Patient charts are placed on a clip board and small, metal clips are clipped onto each chart that designates the current status of the patient. The metal clips are color coded and have a particular "status" printed on the ends of the clips. Some of the printed "status" codes include the following phrases:

Waiting for x-ray

To x-ray

X-ray done

US (Ultrasound)

Pelvic

UA (Urinalysis)

Thus, the clips provide caregivers a visual clue as to a patient's current status in the ED process. Another interesting aspect of their control process is their rack used to house charts that are not currently being used. They developed a large (approximately 6 feet long by 3 feet high), multibay, open-ended on two sides rack that held patient charts. The ED personnel could easily view the work in process from a considerable distance. One column of the rack held charts that were "due to be seen" by the doctor. Charts for new patients, reevaluations, discharged patients, and patients to be seen by the doctor were placed in this rack. The two middle rows of the rack held patient charts that were somewhere in the middle of the treatment process. These two columns were subdivided into several rows – thus each cubbyhole represented a particular ER room. The fourth column in the rack held patient charts for post-discharge patients. This provided a visual cue to personnel to enter final data into the computer system and/or to physically breakdown the chart forms for dispersion to different departments. Eventually, the hospital's plan is to replace the rack system with a computerized "whiteboard" to control the status and flow of work. They anticipate using a plasma screen in which the patient's initials would be used instead of the patient's name. And, acronyms or medical abbreviations would be used to signify patients' particular conditions.

The admissions process was improved by employing a "bed-ahead" process. In certain cases a call is made to the receiving department early in the patient process. By getting started early the identification and preparation of the room and the appropriate paperwork can be prepared to speed the transfer of a patient from the ER into an admissions unit. This helps to clear ED beds, which in turn allows the admission of new patients to the ED.

The physical layout of the ER Department afforded a view of almost all the rooms. The rooms were arranged around a central, open-aired workspace. We observed that the employees work area was large and afforded plenty of space for the various tools they used – it easily held the large rack system, a Pyxis machine, a PACS machine, remote patient monitoring displays, computer systems, triage tool boxes, and any of the clerical supplies they used. Thus, the personnel were within a few steps of reaching any of these tools. Generally, the tools were arranged neatly and large expanses of the desktop surrounding the work center were clutter free. The clutter free desktop allowed nurses and doctors to stop virtually at any point around the work area in order write up reports, notes, charts, or prescriptions. There was one large expanse of open desktop that was inaccessible due to the placement of a gurney against the central work area wall. The "fast-track" area was arranged such that the personnel serving this area had their own workspace separate from the higher acuity workspace. Future improvements include the building of a second Triage room. Thus, each Triage room would handle one patient acuity level – Urgent and Non-urgent. In addition, the hospital plans to divide the waiting room into two separate areas – one area for Urgent patients and the other area for Non-urgent patients. This arrangement would negate the situation in which a lower acuity patient, whom arrived earlier than a higher acuity patient, is irritated when they see the other patient serviced before they are serviced. This may be a legitimate process in terms of getting care to the people that need it the most, but for the patient left waiting, the perception of the process may be unsavory. Thus, the intent is to segregate the two acuity levels in order to improve customer satisfaction.

From a resource perspective the hospital is attempting to get to the point where the Charge Nurse has no patient responsibilities. Currently, the Charge Nurse works exclusively in the MEC and has patient duties.

Since the hospital has been employing the use of an internal Project Improvement team, the ED has realized significant improvements in some key areas. They were able to decrease the length of time for patients admitted to the hospital - from arrival to admission – by 100 minutes, from 357 minutes to 257 minutes. In addition, they decreased the length of stay (LOS) for patients served by their "fast-track" ED area to the current average of 113 minutes. Their goal is continuously improve their processes until they reach an average of 90 minutes.

Brooke Army Medical Center – San Antonio, Texas

The waiting room area of the ED at the Brooke Army Medical Center (BAMC) was quite large. There were plenty of seats for patients, friends, and family members to sit. The waiting room also had a multitude of wheel chairs staged in the waiting room. Registration was handled at a central desk. The registration process allowed patients classified as Emergent patients to proceed directly to the emergency room. Two other acuity levels were used – Urgent and Non-urgent. Patients classified as Urgent or Non-urgent were processed through one of four Triage rooms located at one end of the waiting room. It was noted that the Triage Nurse could place orders for laboratory and/or radiology diagnostic tests from the Triage room. Non-Urgent patients were routed through a "fast-track" area located down a hallway adjacent to the registration desk.

The actual emergency room was a centrally located, open-aired control center. The area of the control center seemed adequately large, and the area included a central island. The personnel could see most of the rooms within the emergency department. Most of the tools used by the personnel were on the central island, on the desks, on the desktops, and some equipment was arranged around the outside perimeter of the work area. They used a rack system to control the work status and processes for the patients. Several separate racks were used. The racks here were small, made of clear plastic, but it was not readily evident to the layperson as to the flow or status of any particular chart anywhere in the rack system.

The Radiology department was located next to the ER, but the Lab was located on the 5th floor of the building. Thus, lab reports were sent through a delivery mechanism, much like a pneumatic delivery system employed at the drive-up window locations at banks, up to the 5th floor for processing. Interestingly, it was stated that most doctors periodically check the computer information system for the results of lab reports. It was perceived that this was done in lieu of waiting for a hard copy of the lab result being sent back to the ER. The ER employed the use of a PACS system to view radiology reports in the control center.

From a resource perspective BAMC is a little different than other hospitals. Since BAMC is a teaching hospital, a staff physician must sign off on any discharge order given by a resident. Obviously, there are many more sub processes employed within their system in order to coach residents and at the same time maintain a certain quality level of patient care. Also, they employed the use of a Charge Nurse and a Bed Coordinator in order to facilitate a better flow of patients in and out of the ER.

APPENDIX C

MedModel "As-Is" Computer Simulation Program

```
********************************************************************************
*
*                 Formatted Listing of Model:                    *
*   C:\Program Files\MedModel\Models\ctmc50\EmergencyroomHospital77.mod     *
*                                                        *
********************************************************************************

 Time Units:                 Minutes
 Distance Units:              Feet
 Initialization Logic:        ACTIVATE Simulation_Clockconversion()


********************************************************************************
*                        Locations                          *
********************************************************************************

 Name            Cap     Units Stats     Rules        Cost
 ---------------- -------- ----- ----------- -------------- ------------
 Entrance          1         1   Time Series Oldest,
 EMS Entrance
 EMS_Ent          10         1   Time Series Oldest, ,
 Triagewindow      1         1   Time Series Oldest, ,
 Triage_queue     INFINITE 1     Time Series Oldest, ,
 Triage            1         1   Time Series Oldest, ,
 Waiting_room      1    15   1   Time Series Oldest, ,
 Reg_queue        INFINITE 1     Time Series Oldest, ,
 Registration      2         1   Time Series Oldest, ,
 Waiting_Room 2   60         1   Time Series Oldest, , First
 Treatmentroom_E1  1         1   Time Series Oldest, ,
 Treatmentroom_E2  1         1   Time Series Oldest, ,
 Treatmentroom_E3  1         1   Time Series Oldest, ,
 Treatmentroom_E4  1         1   Time Series Oldest, ,
```

```
Treatmentroom_E6  1      1   Time Series Oldest, ,
Treatmentroom_E7  1      1   Time Series Oldest, ,

Treatmentroom_E8  1      1   Time Series Oldest, ,
Treatmentroom_E9  1      1   Time Series Oldest, ,
Treatmentroom_E10 1      1   Time Series Oldest, ,
Treatmentroom_E11 1      1   Time Series Oldest, ,
Treatmentroom_E12 1      1   Time Series Oldest, ,
Treatmentroom_G1  1      1   Time Series Oldest, ,
Treatmentroom_G2  1      1   Time Series Oldest, ,
Traumaroom_T1     1      1   Time Series Oldest, ,
Traumaroom_T2     1      1   Time Series Oldest, ,
Traumaroom_T3     1      1   Time Series Oldest, ,
Traumaroom_T4     1      1   Time Series Oldest, ,
Traumaroom_T5     1      1   Time Series Oldest, ,
Traumaroom_T6     1      1   Time Series Oldest, ,
Xrayroom_1        1      1   Time Series Oldest, ,
Xrayroom_2        1      1   Time Series Oldest, ,
Xrayroom_3        1      1   Time Series Oldest, ,
Xrayroom_4        1      1   Time Series Oldest, ,
Ultrasound        1      1   Time Series Oldest, ,
NucMed            1      1   Time Series Oldest, ,
CTscan            1      1   Time Series Oldest, ,
Lab_Results     INFINITE 1   Time Series Oldest, ,
XRay_Results    INFINITE 1   Time Series Oldest, ,
Centrifuge_queue INFINITE 1  Time Series Oldest, ,
Centrifuge        20     1   Time Series Oldest, ,
#
#Location to hold and process x-ray film
XRayReview_room  INFINITE 1  Time Series Oldest, ,
MRI          1      1   Time Series Oldest, ,
#
#Simulated admissions to hospital
Admission       INFINITE 1   Time Series Oldest, , First
#
#Location to hold incoming charts
Chart_rack      INFINITE 1   Time Series Oldest, ,
```

Flee 1 1 Time Series Oldest, ,
#
#EMS Exit
EMS_Exit 1 1 Time Series Oldest, ,
#
#Phone Location
Phone 1 1 Time Series Oldest, ,
#
#Phone Queue
Phone_Queue INFINITE 1 Time Series Oldest, ,

****
* Entities *
****

Name	Speed (fpm)	Stats	Cost
Patient	60	Time Series	
Lab_Sample	80	Time Series	
XRay_film	80	Time Series	
Chart	80	Time Series	
US_result	80	Time Series	
MRI_result	80	Time Series	
NMed_result	80	Time Series	
CT_result	80	Time Series	
Phone_call	10	Time Series	

****
* Path Networks *
****

Name	Type	T/S	From	To	BI	Dist/Time	Speed Factor
Net1	Passing	Speed & Distance	EntExit	Frontdoor	Bi	10.65	1
			Frontdoor	Wait_room	Bi	7.91	1

N1	N2	Bi	9.73	1
N2	N3	Bi	13.07	1
N8	N5	Bi	35.38	1
N3	N4	Bi	21.91	1
N4	N7	Bi	11.05	1
N5	N6	Bi	12.18	1
N8	N9	Bi	27.08	1
N10	N9	Bi	13.39	1
N11	N10	Bi	22.85	1
N14	N11	Bi	49.59	1
N15	N16	Bi	29.10	1
N11	N15	Bi	17.74	1
N17	N10	Bi	10.20	1
N18	N9	Bi	5.51	1
N19	N18	Bi	20.71	1
N20	N15	Bi	8.47	1
N21	N20	Bi	5.58	1
N24	N25	Bi	9.70	1
N26	N1	Bi	24.20	1
N27	N26	Bi	28.30	1
N28	N27	Bi	15.82	1
N29	N28	Bi	11.90	1
N30	N29	Bi	2.45	1
N31	N28	Bi	8.00	1
N32	N29	Bi	13.87	1
N33	N27	Bi	4.57	1
N34	N33	Bi	6.56	1
N35	N18	Bi	23.14	1
N36	N35	Bi	10.22	1
N37	N35	Bi	13.00	1
N38	N37	Bi	5.78	1
N39	N37	Bi	11.81	1
N40	N39	Bi	6.39	1
N41	N22	Bi	5.71	1
N6	N42	Bi	11.26	1
N42	EMSEntrance	Bi	10.97	1
EMSEntrance	N43	Bi	11.95	1

N43	N44	Bi	12.23	1
N44	N45	Bi	11.92	1
N45	N12	Bi	7.00	1
N12	N46	Bi	10.26	1
N46	N7	Bi	11.92	1
N47	Wait_room	Bi	14.11	1
N47	N3	Bi	11.29	1
Triagehome	N47	Bi	8.77	1
N49	N7	Bi	9.74	1
N50	N49	Bi	7.30	1
N51	N50	Bi	6.08	1
N52	N51	Bi	5.47	1
N53	N52	Bi	4.27	1
N53	N6	Bi	9.47	1
Doctorhome	N49	Bi	3.65	1
Nursehome	N50	Bi	4.57	1
Nursetechhome	N52	Bi	3.95	1
N57	N51	Bi	4.86	1
N4	N59	Bi	10.34	1
N58	N59	Bi	4.90	1
N59	N60	Bi	11.56	1
N60	N61	Bi	9.81	1
N61	N5	Bi	10.35	1
N2	N22	Bi	22.72	1
N22	N62	Bi	8.82	1
N62	N8	Bi	10.71	1
MECPAhome	N62	Bi	3.66	1
N1	Registhome	Bi	14.61	1
Registhome	Recept1	Bi	4.87	1
Recept1	Recept2	Bi	2.75	1
N48	Triagehome	Bi	6.67	1
Wait_room	N64	Bi	14.51	1
N64	N1	Bi	10.50	1
N5	N65	Bi	12.06	1
N5	N66	Bi	11.02	1
N6	N67	Bi	13.62	1
N42	N68	Bi	12.47	1

EMSEntrance	N77	Bi	11.83	1
N43	N76	Bi	7.89	1
N44	N75	Bi	6.80	1
N45	N74	Bi	7.40	1
N12	N73	Bi	14.27	1
N12	N72	Bi	11.65	1
N46	N71	Bi	9.15	1
N61	N70	Bi	7.32	1
N60	N69	Bi	8.90	1
N41	NE3	Bi	8.31	1
N41	NE4	Bi	3.67	1
N45	N81	Bi	11.25	1
N43	N80	Bi	10.38	1
N8	MECNursehome	Bi	4.35	1
Wait_room	OffShift	Bi	177.79	1
Labhome	N29	Bi	4.13	1
Resphome	N55	Bi	9.60	1
N55	N54	Bi	28.62	1
N54	N39	Bi	11.75	1
Radiolhome	N54	Bi	29.33	1
N19	Radiolhome	Bi	17.57	1
N16	N79	Bi	13.26	1
N79	N78	Bi	11.36	1
N78	N63	Bi	13.39	1
N63	N56	Bi	4.32	1
N56	N17	Bi	11.62	1
N21	N82	Bi	5.25	1
N82	N83	Bi	5.44	1
N83	N84	Bi	5.81	1
N84	N78	Bi	4.91	1
N78	Radiolhome	Bi	14.91	1
N25	N22	Bi	5.18	1
N23	N25	Bi	5.61	1
MECOffShift	MECNursehome	Bi	13.57	1
ERClerkhome	N50	Bi	3.71	1
OffShift	ERClerkOffshift	Bi	4.30	1
OffShift	Triage_TechOffshift	Bi	5.32	1

OffShift	Register_TechOffshift	Bi	5.97	1
OffShift	Nurse_TechOffShift	Bi	5.23	1
OffShift	Rad_TechOffShift	Bi	3.05	1

```
***************************************************************************
*                    Interfaces                        *
***************************************************************************
```

Net	Node	Location
Net1	Frontdoor	Triage_queue
	EntExit	Flee
	EntExit	Entrance
	Wait_room	Waiting_Room2
	N48	Triagewindow
	Wait_room	Waiting_room1
	N64	Reg_queue
	N65	Traumaroom_T4
	N66	Traumaroom_T3
	N67	Traumaroom_T2
	N68	Traumaroom_T1
	N77	Treatmentroom_E12
	N76	Treatmentroom_E11
	N69	Traumaroom_T6
	N75	Treatmentroom_E10
	N74	Treatmentroom_E9
	N73	Treatmentroom_G2
	N72	Treatmentroom_G1
	N71	Treatmentroom_E6
	N70	Traumaroom_T5
	N80	Treatmentroom_E8
	N81	Treatmentroom_E7
	Triagehome	Triage
	Recept2	Registration
	N14	Admission
	N19	Xrayroom_1

N17	Xrayroom_2
N21	Xrayroom_3
N16	Xrayroom_4
N40	NucMed
N38	Ultrasound
N36	CTscan
N14	MRI
N24	Treatmentroom_E2
NE3	Treatmentroom_E3
NE4	Treatmentroom_E4
N60	XRay_Results
N59	Lab_Results
N30	Centrifuge_queue
N30	Centrifuge
Radiolhome	XRayReview_room
N59	Chart_rack
EMSEntrance	EMS_Exit
N23	Treatmentroom_E1
EMSEntrance	EMS_Ent
ERClerkhome	Phone

****
*   Mapping   *
****

Net	From	To	Dest
Net1	Wait_room	Frontdoor	
	N1	N64	
	N2	N1	
	N3	N47	
	N4	N3	
	N5	N61	
	N6	N53	
	N7	N4	
	N8	N62	

N9	N8
N10	N9
N12	N46
EMSEntrance	N42
N11	N10
N15	N11
N16	N79
N17	N10
N18	N9
N19	N18
N20	N15
N21	N20
N22	N2
N25	N22
N26	N1
N27	N26
N28	N27
N29	N28
N35	N18
N37	N35
N39	N37
N41	N22
N42	N6
N43	N44
N44	N45
N45	N12
N46	N7
N47	Wait_room
N49	N7
N50	N49
N51	N50
N52	N51
N53	N52
N59	N4
N60	N59
N61	N60
N62	N22

Registhome	N1
N64	Wait_room
OffShift	Wait_room
N54	N39
Radiolhome	N19
N56	N17
N63	N56
N78	N63
N79	N78
N82	N83
N83	N84
N84	N78
Wait_room	N64
N1	Registhome
N3	N2
N47	N3
Registhome	Recept1
N64	N1
Wait_room	N47
N1	N2
N2	N3
N3	N4
N4	N7
N5	N6
N6	N42
N7	N49
N8	N5
N12	N45
N22	N62
N42	EMSEntrance
N43	EMSEntrance
N44	N43
N45	N44
N46	N12
N49	N50
N50	N51
N51	N52

N52	N53
N53	N6
N59	N60
N60	N61
N61	N5
N62	N8
N2	N22
N5	N8
N6	N5
N8	N9
N9	N10
N10	N11
N11	N14
N16	N15
N54	Radiolhome
Radiolhome	N78
N78	N84
N79	N16
N82	N21
N83	N82
N84	N83
N10	N17
N11	N15
N15	N16
N17	N56
N18	N19
N19	Radiolhome
N37	N39
N39	N54
N56	N63
N63	N78
N78	N79
N20	N21
N21	N82
N9	N18
N15	N20
N78	Radiolhome

N22	N25
N25	N24
N1	N26
N26	N27
N27	N28
N28	N29
N29	N30
N18	N35
N35	N36
N35	N37
N37	N38
Radiolhome	N54
N39	N40
N47	Triagehome
N49	Doctorhome
N50	Nursehome
N52	Nursetechhome
N4	N59
N62	MECPAhome
N5	N65
N5	N66
N6	N67
N42	N68
N60	N69
N61	N70
N7	N46
EMSEntrance	N43
N46	N71
N12	N72
N12	N73
N45	N74
N44	N75
N43	N76
EMSEntrance	N77
N22	N41
N41	NE3
N41	NE4

```
N43        N80
N45        N81
N8         MECNursehome
Wait_room  OffShift
N29        Labhome
N54        N55
N25        N23
N50        ERClerkhome
OffShift   ERClerkOffshift
OffShift   Triage_TechOffshift
OffShift   Register_TechOffshift
OffShift   Nurse_TechOffShift
OffShift   Rad_TechOffShift


****************************************************************************
*                        Resources                        *
****************************************************************************

                      Res     Ent
 Name         Units Stats    Search  Search Path         Motion        Cost
 ------------- ----- --------- -------- ------ ------------------- -------------- ------------
 Triage_Tech   1    By Unit  Closest Oldest Net1          Empty: 114 fpm
                             Home: Triagehome   Full: 114 fpm
                             (Return)

 Triage_Nurse  1    By Unit  Closest Oldest Net1          Empty: 114 fpm
                             Home: Triagehome   Full: 114 fpm
                             (Return)

 Register_Tech 2    By Unit  Closest Oldest Net1          Empty: 114 fpm
                             Home: Registhome   Full: 114 fpm
                             (Return)

 Doctor           1    By Unit  Closest Oldest Net1          Empty: 114 fpm
                             Home: Doctorhome   Full: 114 fpm
                             (Return)
```

MECPA	1	By Unit	Closest Oldest Net1 Home: MECPAhome (Return)	Empty: 114 fpm Full: 114 fpm
MECNurse	1	By Unit	Closest Oldest Net1 Home: MECNursehome (Return)	Empty: 114 fpm Full: 114 fpm
Nurse	3	By Unit	Closest Oldest Net1 Home: Nursehome (Return)	Empty: 114 fpm Full: 114 fpm
Nurse_Tech	1	By Unit	Closest Oldest Net1 Home: Nursetechhome (Return)	Empty: 114 fpm Full: 114 fpm
Lab_Tech	4	By Unit	Closest Oldest Net1 Home: Labhome (Return)	Empty: 114 fpm Full: 114 fpm
Rad_Tech	4	By Unit	Closest Oldest Net1 Home: Radiolhome (Return)	Empty: 114 fpm Full: 114 fpm
Resp_Tech	1	By Unit	Closest Oldest Net1 Home: Resphome (Return)	Empty: 114 fpm Full: 114 fpm
ER_Clerk	1	By Unit	Closest Oldest Net1 Home: ERClerkhome (Return)	Empty: 114 fpm Full: 114 fpm

```
********************************************************************************
*                    Processing                    *
********************************************************************************

                    Process                     Routing

Entity   Location     Operation        Blk  Output    Destination     Rule    Move Logic
------------ ------------------ ------------------  ---- ------------ ----------------- ------- ------------
Patient  Entrance     aPt_Type=dPt_Dist()
              INC vPt_ID
              aPt_ID = vPt_ID
              aRegistered = 0
              aNeed_Admit = 0
              aPt_Arrive_Time = CLOCK()
              INC vPatients_Insystem
                                        1   Patient   Triage_queue   FIRST 1  MOVE ON Net1

Patient  EMS_Ent      GRAPHIC 5
              WAIT 3 MIN
              IF vTrauma_Divert >= 10 THEN
                     BEGIN
                            ROUTE 3
                     END
              ELSE
                     BEGIN
                            INC vTrauma_Divert
                            INC vPt_ID
                            aPt_ID = vPt_ID
                            aPt_Type=dEMSPt_Dist()
                            aNeedTrauma = 1
                            aRegistered = 0
                            aNeed_Admit = 0
                            INC vPatients_Insystem
                            aPt_Arrive_Time = CLOCK()
```

```
            GET Nurse OR Nurse_Tech
            IF aPt_Type = 3 OR aPt_Type = 2 THEN
                ROUTE 1
            ELSE
                ROUTE 2
END

                1     Patient   Traumaroom_T1    FIRST 1  GRAPHIC 3
                          MOVE WITH Nurse OR Nurse_Tech THEN FREE
                      Patient   Traumaroom_T2    FIRST    GRAPHIC 3
                          MOVE WITH Nurse OR Nurse_Tech THEN FREE
                      Patient   Traumaroom_T3    FIRST    GRAPHIC 3
                          MOVE WITH Nurse OR Nurse_Tech THEN FREE
                      Patient   Traumaroom_T4    FIRST    GRAPHIC 3
                          MOVE WITH Nurse OR Nurse_Tech THEN FREE
                      Patient   Traumaroom_T5    FIRST    GRAPHIC 3
                          MOVE WITH Nurse OR Nurse_Tech THEN FREE
                      Patient   Traumaroom_T6    FIRST    GRAPHIC 3
                          MOVE WITH Nurse OR Nurse_Tech THEN FREE
                      Patient   Treatmentroom_E9  FIRST   GRAPHIC 3
                          MOVE WITH Nurse OR Nurse_Tech THEN FREE
                      Patient   Treatmentroom_E10 FIRST   GRAPHIC 3
                          MOVE WITH Nurse OR Nurse_Tech THEN FREE
                      Patient   Treatmentroom_E11 FIRST   GRAPHIC 3
                          MOVE WITH Nurse OR Nurse_Tech THEN FREE

                      Patient   Treatmentroom_E12 FIRST   GRAPHIC 3
                          MOVE WITH Nurse OR Nurse_Tech THEN FREE

                2     Patient   Treatmentroom_E9  FIRST 1 GRAPHIC 3
                          MOVE WITH Nurse OR Nurse_Tech THEN FREE
                      Patient   Treatmentroom_E10 FIRST   GRAPHIC 3
                          MOVE WITH Nurse OR Nurse_Tech THEN FREE
                            Patient   Treatmentroom_E11 FIRST   GRAPHIC 3
                          MOVE WITH Nurse OR Nurse_Tech THEN FREE
                      Patient   Treatmentroom_E12 FIRST   GRAPHIC 3
                          MOVE WITH Nurse OR Nurse_Tech THEN FREE
```

```
                                                Patient   Traumaroom_T1   FIRST   GRAPHIC 3
                                                     MOVE WITH Nurse OR Nurse_Tech THEN FREE
                                                Patient   Traumaroom_T2   FIRST   GRAPHIC 3
                                                     MOVE WITH Nurse OR Nurse_Tech THEN FREE
                                                Patient   Traumaroom_T3   FIRST   GRAPHIC 3
                                                     MOVE WITH Nurse OR Nurse_Tech THEN FREE
                                                Patient   Traumaroom_T4   FIRST   GRAPHIC 3
                                                     MOVE WITH Nurse OR Nurse_Tech THEN FREE
                                                Patient   Traumaroom_T5   FIRST   GRAPHIC 3
                                                     MOVE WITH Nurse OR Nurse_Tech THEN FREE
                                                Patient   Traumaroom_T6   FIRST   GRAPHIC 3
                                                     MOVE WITH Nurse OR Nurse_Tech THEN FREE

                                          3     Patient   EMS_Exit     FIRST 1  MOVE ON Net1
                                                     GRAPHIC 5

Patient   Triage_queue                    1     Patient   Triagewindow   FIRST 1

Patient   Triagewindow   IF aPt_Type = 3 AND vTrauma_Divert >= 10 THEN
                   BEGIN
                         ROUTE 3
                   END
              IF aPt_Type = 3 AND vTrauma_Divert < 10 THEN
                   BEGIN
                         aNeedTrauma = 1
                         INC vTrauma_Divert
                         GET Triage_Tech OR Triage_Nurse
                         WAIT 1 MIN
                         ROUTE 1
                   END
              IF aPt_Type = 2 THEN
                   BEGIN
                         aNeedTrauma = BI(1,.67)
                   END
              IF aPt_Type = 2 AND aNeedTrauma = 1 AND vTrauma_Divert >= 10 THEN
                   BEGIN
```

```
            ROUTE 3
      END
IF aPt_Type = 2 AND aNeedTrauma = 1 AND vTrauma_Divert < 10 THEN
      BEGIN
            INC vTrauma_Divert
            GET Triage_Tech OR Triage_Nurse
            WAIT 1 MIN
            ROUTE 1
      END
IF aPt_Type = 0 THEN
      BEGIN
            GET Triage_Tech OR Triage_Nurse
            WAIT 0.25 MIN
            FREE ALL
            ROUTE 2
      END
IF aPt_Type = 1 THEN
      BEGIN
            GET Triage_Tech OR Triage_Nurse
            WAIT 0.25 MIN
            FREE ALL
            ROUTE 2
      END
IF aPt_Type = 2 AND aNeedTrauma = 0 THEN
      BEGIN
            GET Triage_Tech OR Triage_Nurse
            WAIT 0.25 MIN
            FREE ALL
            ROUTE 2
      END


                  1      Patient    Traumaroom_T1    FIRST    GRAPHIC 1
                              MOVE WITH Triage_Tech OR Triage_Nurse THEN FREE
                         Patient    Traumaroom_T2    FIRST    GRAPHIC 1
```

```
                                         MOVE WITH Triage_Tech OR Triage_Nurse THEN FREE
                                    Patient    Traumaroom_T3    FIRST    GRAPHIC 1
                                         MOVE WITH Triage_Tech OR Triage_Nurse THEN FREE
                                    Patient    Traumaroom_T4    FIRST    GRAPHIC 1
                                         MOVE WITH Triage_Tech OR Triage_Nurse THEN FREE
                                    Patient    Traumaroom_T5    FIRST    GRAPHIC 1
                                         MOVE WITH Triage_Tech OR Triage_Nurse THEN FREE
                                    Patient    Traumaroom_T6    FIRST    GRAPHIC 1
                                         MOVE WITH Triage_Tech OR Triage_Nurse THEN FREE
                                    Patient    Treatmentroom_E9  FIRST   GRAPHIC 1
                                         MOVE WITH Triage_Tech OR Triage_Nurse THEN FREE
                                    Patient    Treatmentroom_E10 FIRST   GRAPHIC 1
                                         MOVE WITH Triage_Tech OR Triage_Nurse THEN FREE
                                    Patient    Treatmentroom_E11 FIRST   GRAPHIC 1
                                         MOVE WITH Triage_Tech OR Triage_Nurse THEN FREE
                                    Patient    Treatmentroom_E12 FIRST   GRAPHIC 1
                                         MOVE WITH Triage_Tech OR Triage_Nurse THEN FREE

                               2    Patient    Waiting_room1    FIRST 1  GRAPHIC 1
                                         MOVE FOR 0.25 MIN

                               3    Patient    EMS_Exit         FIRST 1  GRAPHIC 1
                                         MOVE ON Net1

Patient    Waiting_room1    GRAPHIC 2
           GET Triage_Nurse

                               1    Patient    Triage           FIRST 1  MOVE WITH Triage_Nurse

Patient    Triage           GRAPHIC 2
           WAIT T(2., 3.03, 17.8)
           FREE Triage_Nurse
                               1    Patient    Reg_queue        FIRST 1  GRAPHIC 1
                                         MOVE ON Net1
```

```
Patient    Reg_queue                    1        Patient    Registration    FIRST 1

Patient    Registration GRAPHIC 2
               GET Register_Tech
               WAIT 1.+P6(5.02, 14.8, 21.9)
               INC aRegistered
               CREATE 1 AS Chart TAKE Register_Tech

                                        1        Patient    Waiting_Room2    FIRST 1  GRAPHIC 1

Patient    Waiting_Room2    GRAPHIC 2
               WAIT 2 MIN
               IF aPt_Type = 0 AND vClock_hour >= 11 AND (vClock_hour < 23 AND vClock_min <= 45) THEN
                         ROUTE 1
               ELSE
                         ROUTE 2


                                        1        Patient    Treatmentroom_E1  FIRST 1  GRAPHIC 1
                                                     MOVE WITH MECNurse
                                                       Patient    Treatmentroom_E2  FIRST    GRAPHIC 1
                                                     MOVE WITH MECNurse
                Patient    Treatmentroom_E3  FIRST    GRAPHIC 1
                                                     MOVE WITH MECNurse
                                                       Patient    Treatmentroom_E4  FIRST    GRAPHIC 1
                                                     MOVE WITH MECNurse

                                        2        Patient    Treatmentroom_E6  FIRST 1  GRAPHIC 1
                                                     MOVE WITH Nurse
                Patient    Treatmentroom_E7  FIRST    GRAPHIC 1
                                                     MOVE WITH Nurse
                                                 Patient    Treatmentroom_E8  FIRST    GRAPHIC 1
                                                     MOVE WITH Nurse
                                                 Patient    Treatmentroom_G1  FIRST    GRAPHIC 1
                                                     MOVE WITH Nurse
                                                 Patient    Treatmentroom_G2  FIRST    GRAPHIC 1
```

```
                                        MOVE WITH Nurse
                                Patient     Treatmentroom_E9  FIRST    INC vTrauma_Divert
                                        GRAPHIC 1
                                        MOVE WITH Nurse
                                Patient     Treatmentroom_E10 FIRST    INC vTrauma_Divert
                                        GRAPHIC 1
                                        MOVE WITH Nurse
                                Patient     Treatmentroom_E11 FIRST    INC vTrauma_Divert
                                        GRAPHIC 1
                                        MOVE WITH Nurse
                                Patient     Treatmentroom_E12 FIRST    INC vTrauma_Divert
                                        GRAPHIC 1
                                        MOVE WITH Nurse

Chart    Registration                1  Chart   Chart_rack    FIRST 1  MOVE WITH Register_Tech THEN FREE

Chart    Chart_rack    MATCH aPt_ID
                                     1  Chart   Treatmentroom_E1  JOIN 1
                                        Chart   Treatmentroom_E2  JOIN
                                        Chart   Treatmentroom_E3  JOIN
                                        Chart   Treatmentroom_E4  JOIN
                                        Chart   Treatmentroom_E6  JOIN
                                        Chart   Treatmentroom_E7  JOIN
                                        Chart   Treatmentroom_E8  JOIN
                                        Chart   Treatmentroom_E9  JOIN
                                        Chart   Treatmentroom_E10 JOIN
                                        Chart   Treatmentroom_E11 JOIN
                                        Chart   Treatmentroom_E12 JOIN
                                        Chart   Treatmentroom_G1  JOIN
                                        Chart   Treatmentroom_G2  JOIN
                                        Chart   Traumaroom_T1     JOIN
                                        Chart   Traumaroom_T2     JOIN
                                        Chart   Traumaroom_T3     JOIN
                                        Chart   Traumaroom_T4     JOIN
                                        Chart   Traumaroom_T5     JOIN
```

Chart Traumaroom_T6 JOIN

```
Patient   Traumaroom_T1 THRU Traumaroom_T6
                GRAPHIC 3
             IF aPt_Type = 3 THEN
                BEGIN
                     JOINTLY GET 1 Doctor, 100 AND (1 Nurse_Tech, 100 OR 1 Nurse, 100) AND 1 Register_Tech, 100
                     WAIT T(0.5,7,10,1)
                     INC aRegistered
                     FREE Register_Tech
                     WAIT 2 MIN
                     FREE ALL
                     aNeed_Rad = BI(1,.97)
                     aNeed_Lab = BI(1,.94)
                     aNeed_Resp = BI(1,.50)
                     aNeed_US = BI(1,.03)
                     aNeed_CT = BI(1,.20)
                     aNeed_MRI = BI(1,.01)
                     aNeed_NMed = BI(1,.001)
             IF aNeed_Rad = 1 THEN
                BEGIN
                     GET Rad_Tech
                     Route 1
                     Graphic 4
                     MATCH aPt_ID
                     JOIN 1 Patient
                     Graphic 3
                     FREE Rad_Tech
                     MATCH aPt_ID
                     JOIN 1 XRay_film
                END
             IF aNeed_Lab = 1 THEN
                BEGIN
                     GET Nurse OR Nurse_Tech
                     WAIT T(2,8,25,1)
                     CREATE 1 AS Lab_Sample TAKE ALL
                     Graphic 4
```

```
                    MATCH aPt_ID
                    JOIN 1 Lab_Sample
                    Graphic 3
          END
IF aNeed_Resp = 1 THEN
          BEGIN
                    GET Resp_Tech
                    WAIT 3 MIN
                    FREE Resp_Tech
                    WAIT 20 MIN
                    GET Resp_Tech
                    WAIT 3 MIN
                    FREE Resp_Tech
          END
IF aNeed_US = 1 THEN
          BEGIN
                    GET Rad_Tech
                    Route 3
                    Graphic 4
                    MATCH aPt_ID
                    JOIN 1 Patient
                    Graphic 3
                    FREE Rad_Tech
                    MATCH aPt_ID
                    JOIN 1 US_result
          END
IF aNeed_CT = 1 THEN
          BEGIN
                    GET Rad_Tech
                    Route 4
                    Graphic 4
                    MATCH aPt_ID
                    JOIN 1 Patient
                    Graphic 3
                    FREE Rad_Tech
                    MATCH aPt_ID
                    JOIN 1 CT_result
```

```
        END
IF aNeed_MRI = 1 THEN
        BEGIN
                GET Rad_Tech
                Route 5
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 MRI_result
        END
IF aNeed_NMed = 1 THEN
        BEGIN
                GET Rad_Tech
                Route 6
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 NMed_result
        END
aNeed_Admit = BI(1,.33)
IF aNeed_Admit = 1 THEN
        BEGIN
                WAIT T(30,38,90,1)
                GET Nurse_Tech OR Nurse
                ROUTE 2
        END
ELSE
        BEGIN
                GET Nurse_Tech OR Nurse
                WAIT 11 MIN
                FREE ALL
```

```
            GET Nurse
            WAIT 11 MIN
            FREE Nurse
            GET Doctor
            WAIT 11 MIN
            FREE Doctor
            GET Nurse
            WAIT N(5.50,6.36,1)
            FREE Nurse
            ROUTE 7
      END
END
ELSE
IF aPt_Type = 2 AND aRegistered = 0 THEN
      BEGIN
            JOINTLY GET 1 Doctor, 100 AND (1 Nurse_Tech, 100 OR 1 Nurse, 100) AND 1 Register_Tech, 100
            WAIT T(0.5,7,10,1)
            INC aRegistered
            FREE Register_Tech
            WAIT 2 MIN
            FREE ALL
            aNeed_Rad = BI(1,.94)
            aNeed_Lab = BI(1,.97)
            aNeed_Resp = BI(1,.50)
            aNeed_US = BI(1,.10)
            aNeed_CT = BI(1,.20)
            aNeed_MRI = BI(1,.02)
IF aNeed_Rad = 1 THEN
      BEGIN
            GET Rad_Tech
            Route 1
            Graphic 4
            MATCH aPt_ID
            JOIN 1 Patient
            Graphic 3
            FREE Rad_Tech
            MATCH aPt_ID
```

```
                JOIN 1 XRay_film
        END
IF aNeed_Lab = 1 THEN
        BEGIN
                GET Nurse OR Nurse_Tech
                WAIT T(2,8,25,1)
                CREATE 1 AS Lab_Sample TAKE ALL
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Lab_Sample
                Graphic 3
        END
IF aNeed_Resp = 1 THEN
        BEGIN
                GET Resp_Tech
                WAIT 3 MIN
                FREE Resp_Tech
                WAIT 20 MIN
                GET Resp_Tech
                WAIT 3 MIN
                FREE Resp_Tech
        END
IF aNeed_US = 1 THEN
        BEGIN
                GET Rad_Tech
                Route 3
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 US_result
        END
IF aNeed_CT = 1 THEN
        BEGIN
                GET Rad_Tech
```

```
            Route 4
            Graphic 4
            MATCH aPt_ID
            JOIN 1 Patient
            Graphic 3
            FREE Rad_Tech
            MATCH aPt_ID
            JOIN 1 CT_result
        END
IF aNeed_MRI = 1 THEN
        BEGIN
            GET Rad_Tech
            Route 5
            Graphic 4
            MATCH aPt_ID
            JOIN 1 Patient
            Graphic 3
            FREE Rad_Tech
            MATCH aPt_ID
            JOIN 1 MRI_result
        END
aNeed_Admit = BI(1,.294)
IF aNeed_Admit = 1 THEN
        BEGIN
            WAIT T(30,38,90,1)
            GET Nurse_Tech OR Nurse
            ROUTE 2
        END
ELSE
        BEGIN
            GET Nurse_Tech OR Nurse
            WAIT 11 MIN
            FREE ALL
            GET Nurse
            WAIT 11 MIN
            FREE Nurse
            GET Doctor
```

```
                WAIT 11 MIN
                FREE Doctor
                GET Nurse
                WAIT N(5.50,6.36,1)
                FREE Nurse
                ROUTE 7
        END
END
ELSE
IF aPt_Type = 1 AND aRegistered = 0 THEN
        BEGIN
                JOINTLY GET 1 Doctor, 100 AND (1 Nurse_Tech, 100 OR 1 Nurse, 100) AND 1 Register_Tech, 100
                WAIT T(.5,7,10,1)
                INC aRegistered
                FREE Register_Tech
                WAIT 2 MIN
                FREE ALL
                aNeed_Rad = BI(1,.40)
                aNeed_Lab = BI(1,.61)
                aNeed_Resp = BI(1,.20)
                aNeed_US = BI(1,.10)
                aNeed_CT = BI(1,.15)
IF aNeed_Rad = 1 THEN
        BEGIN
                GET Rad_Tech
                Route 1
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 XRay_film
        END
IF aNeed_Lab = 1 THEN
        BEGIN
                GET Nurse OR Nurse_Tech
```

```
            WAIT T(2,8,25,1)
            CREATE 1 AS Lab_Sample TAKE ALL
            Graphic 4
            MATCH aPt_ID
            JOIN 1 Lab_Sample
            Graphic 3
      END
IF aNeed_Resp = 1 THEN
      BEGIN
            GET Resp_Tech
            WAIT 3 MIN
            FREE Resp_Tech
            WAIT 20 MIN
            GET Resp_Tech
            WAIT 3 MIN
            FREE Resp_Tech
      END
IF aNeed_US = 1 THEN
      BEGIN
            GET Rad_Tech
            Route 3
            Graphic 4
            MATCH aPt_ID
            JOIN 1 Patient
            Graphic 3
            FREE Rad_Tech
            MATCH aPt_ID
            JOIN 1 US_result
      END
IF aNeed_CT = 1 THEN
      BEGIN
            GET Rad_Tech
            Route 4
            Graphic 4
            MATCH aPt_ID
            JOIN 1 Patient
            Graphic 3
```

```
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 CT_result
        END
aNeed_Admit = BI(1,.096)
IF aNeed_Admit = 1 THEN
        BEGIN
                WAIT T(30,38,90,1)
                GET Nurse_Tech OR Nurse
                ROUTE 2
        END
ELSE
        BEGIN
                GET Nurse OR Nurse_Tech
                WAIT 12.25 MIN
                FREE ALL
                GET Doctor
                WAIT 2 MIN
                FREE Doctor
                GET Nurse
                WAIT N(3.59,3.25,1)
                FREE Nurse
                ROUTE 7
        END
END
```

```
1       Patient   Xrayroom_1     FIRST 1  MOVE WITH Rad_Tech
        Patient   Xrayroom_2     FIRST    MOVE WITH Rad_Tech
        Patient   Xrayroom_3     FIRST    MOVE WITH Rad_Tech
        Patient   Xrayroom_4     FIRST    MOVE WITH Rad_Tech
2       Patient   Admission      FIRST 1  DEC vTrauma_Divert
            MOVE FOR 15 MIN
            FREE ALL
3       Patient   Ultrasound     FIRST 1  GRAPHIC 3
            MOVE WITH Rad_Tech
```

```
            4       Patient   CTscan        FIRST 1  GRAPHIC 3
                          MOVE WITH Rad_Tech
            5       Patient   MRI          FIRST 1  GRAPHIC 3
                          MOVE WITH Rad_Tech
            6       Patient   NucMed        FIRST 1  GRAPHIC 3
                          MOVE WITH Rad_Tech
            7       Patient   Flee         FIRST 1  DEC vTrauma_Divert
                          GRAPHIC 1
                          MOVE ON Net1

Patient   Treatmentroom_E1  THRU Treatmentroom_E4
     GRAPHIC 3
     MATCH aPt_ID
     Join 1 Chart
     WAIT 2.75 MIN
     FREE MECNurse
     GET MECPA, 200
     WAIT 5 MIN
     FREE MECPA
     aNeed_Lab = BI(1,.125)
     aNeed_Rad = BI(1,.45)
     aNeed_Resp = BI(1,.085)
     IF aNeed_Rad = 1 THEN
          BEGIN
               GET Rad_Tech
               Route 1
               Graphic 4
               MATCH aPt_ID
               JOIN 1 Patient
               Graphic 3
               FREE Rad_Tech
               MATCH aPt_ID
               JOIN 1 XRay_film, 200
          END
     IF aNeed_Lab = 1 THEN
          BEGIN
```

```
                    GET MECNurse, 200
                    WAIT T(2,8,25,1)
                    CREATE 1 AS Lab_Sample TAKE MECNurse
                    Graphic 4
                    MATCH aPt_ID
                    JOIN 1 Lab_Sample, 200
                    Graphic 3
          END
IF aNeed_Resp = 1 THEN
          BEGIN
                    GET Resp_Tech
                    WAIT 3 MIN
                    FREE Resp_Tech
                    WAIT 20 MIN
                    GET Resp_Tech
                    WAIT 3 MIN
                    FREE Resp_Tech
          END
GET MECNurse, 200
WAIT 5 MIN
FREE MECNurse
GET MECPA, 200
WAIT 5 MIN
FREE MECPA
GET MECNurse, 200
WAIT N(2.66,2.24,1)
FREE MECNurse
Route 2
```

```
1     Patient   Xrayroom_1     FIRST 1  MOVE WITH Rad_Tech
      Patient   Xrayroom_2     FIRST    MOVE WITH Rad_Tech
      Patient   Xrayroom_3     FIRST    MOVE WITH Rad_Tech
```

```
                                        Patient    Xrayroom_4       FIRST    MOVE WITH Rad_Tech

                                2           Patient    Flee            FIRST 1  GRAPHIC 1  MOVE ON Net1
```

Patient **Treatmentroom_E6 THRU Treatmentroom_E8 AND Treatmentroom_G1 AND Treatmentroom_G2**

```
GRAPHIC 3
MATCH aPt_ID
JOIN 1 Chart
WAIT 2.75 MIN
FREE Nurse
GET Doctor
WAIT 5 MIN
FREE Doctor
IF aPt_Type = 0 THEN
     BEGIN
aNeed_Lab = BI(1,.125)
aNeed_Rad = BI(1,.45)
aNeed_Resp = BI(1,.085)
IF aNeed_Rad = 1 THEN
     BEGIN
          GET Rad_Tech
          Route 1
          Graphic 4
          MATCH aPt_ID
          JOIN 1 Patient
          Graphic 3
          FREE Rad_Tech
          MATCH aPt_ID
          JOIN 1 XRay_film
     END
IF aNeed_Lab = 1 THEN
     BEGIN
          GET Nurse OR Nurse_Tech
          WAIT T(2,8,25,1)
          CREATE 1 AS Lab_Sample TAKE ALL
          Graphic 4
          MATCH aPt_ID
```

```
                JOIN 1 Lab_Sample
                Graphic 3
        END
IF aNeed_Resp = 1 THEN
        BEGIN
                GET Resp_Tech
                WAIT 3 MIN
                FREE Resp_Tech
                WAIT 20 MIN
                GET Resp_Tech
                WAIT 3 MIN
                FREE Resp_Tech
        END
                GET Nurse OR Nurse_Tech
                WAIT 5.5 MIN
                FREE ALL
                GET Doctor
                WAIT 5 MIN
                FREE Doctor
                GET Nurse
                WAIT N(2.66,2.24,1)
                FREE Nurse
                Route 2
        END
ELSE
IF aPt_Type = 1 THEN
        BEGIN
                aNeed_Lab = BI(1,.61)
                aNeed_Rad = BI(1,.35)
                aNeed_Resp = BI(1,.20)
                aNeed_US = BI(1,.07)
                aNeed_CT = BI(1,.10)
                GET Nurse OR Nurse_Tech
                WAIT 10 MIN
                FREE ALL
IF aNeed_Rad = 1 THEN
        BEGIN
```

```
                GET Rad_Tech
                Route 1
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 XRay_film
        END
IF aNeed_Lab = 1 THEN
        BEGIN
                GET Nurse OR Nurse_Tech
                WAIT T(2,8,25,1)
                CREATE 1 AS Lab_Sample TAKE ALL
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Lab_Sample
                Graphic 3
        END
IF aNeed_Resp = 1 THEN
        BEGIN
                GET Resp_Tech
                WAIT 3 MIN
                FREE Resp_Tech
                WAIT 20 MIN
                GET Resp_Tech
                WAIT 3 MIN
                FREE Resp_Tech
        END
IF aNeed_US = 1 THEN
        BEGIN
                GET Rad_Tech
                Route 3
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
```

```
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 US_result
        END
IF aNeed_CT = 1 THEN
        BEGIN
                GET Rad_Tech
                Route 4
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 CT_result
        END
                GET Nurse OR Nurse_Tech
                WAIT 12.25 MIN
                FREE ALL
                GET Doctor
                WAIT 2 MIN
                FREE Doctor
                GET Nurse
                WAIT N(3.59,3.25,1)
                FREE Nurse
                Route 2
        END
ELSE
IF aPt_Type = 2 THEN
        BEGIN
                aNeed_Lab = BI(1,.97)
                aNeed_Rad = BI(1,.90)
                aNeed_Resp = BI(1,.50)
                aNeed_US = BI(1,.07)
                aNeed_CT = BI(1,.20)
                GET Nurse OR Nurse_Tech
```

```
            WAIT 5 MIN
            FREE ALL
            GET Nurse
            WAIT 5 MIN
            FREE Nurse
IF aNeed_Rad = 1 THEN
      BEGIN
            GET Rad_Tech
            Route 1
            Graphic 4
            MATCH aPt_ID
            JOIN 1 Patient
            Graphic 3
            FREE Rad_Tech
            MATCH aPt_ID
            JOIN 1 XRay_film
      END
IF aNeed_Lab = 1 THEN
      BEGIN
            GET Nurse OR Nurse_Tech
            WAIT T(2,8,25,1)
            CREATE 1 AS Lab_Sample TAKE ALL
            Graphic 4
            MATCH aPt_ID
            JOIN 1 Lab_Sample
            Graphic 3
      END
IF aNeed_Resp = 1 THEN
      BEGIN
            GET Resp_Tech
            WAIT 3 MIN
            FREE Resp_Tech
            WAIT 20 MIN
            GET Resp_Tech
            WAIT 3 MIN
            FREE Resp_Tech
      END
```

```
IF aNeed_US = 1 THEN
        BEGIN
                GET Rad_Tech
                Route 3
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 US_result
        END
IF aNeed_CT = 1 THEN
        BEGIN
                GET Rad_Tech
                Route 4
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 CT_result
        END
                GET Nurse_Tech OR Nurse
                WAIT 11 MIN
                FREE ALL
                GET Nurse
                WAIT 11 MIN
                FREE Nurse
                GET Doctor
                WAIT 11 MIN
                FREE Doctor
                GET Nurse
                WAIT N(5.50,6.36,1)
                FREE Nurse
                Route 2
```

```
END
                    1       Patient   Xrayroom_1      FIRST 1  MOVE WITH Rad_Tech
                            Patient   Xrayroom_2      FIRST    MOVE WITH Rad_Tech
                            Patient   Xrayroom_3      FIRST    MOVE WITH Rad_Tech
                            Patient   Xrayroom_4      FIRST    MOVE WITH Rad_Tech

                    2       Patient   Flee         FIRST 1  GRAPHIC 1
                                 MOVE ON Net1
                    3       Patient   Ultrasound      FIRST 1  GRAPHIC 3
                                 MOVE WITH Rad_Tech
                    4       Patient   CTscan          FIRST 1  GRAPHIC 3
                                 MOVE WITH Rad_Tech
                    5       Patient   MRI           FIRST 1  GRAPHIC 3
                                 MOVE WITH Rad_Tech
                    6       Patient   NucMed          FIRST 1  GRAPHIC 3
                                 MOVE WITH Rad_Tech

Patient   Treatmentroom_E9 THRU Treatmentroom_E12
        IF aNeedTrauma = 0 THEN
        BEGIN
              GRAPHIC 3
              MATCH aPt_ID
              JOIN 1 Chart
              WAIT 2.75 MIN
              FREE Nurse
              GET Doctor
              WAIT 5 MIN
              FREE Doctor
        IF aPt_Type = 0 THEN
              BEGIN
        aNeed_Lab = BI(1,.125)
        aNeed_Rad = BI(1,.45)
        aNeed_Resp = BI(1,.085)
        IF aNeed_Rad = 1 THEN
              BEGIN
                     GET Rad_Tech
                     ROUTE 1
```

```
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 XRay_film
        END
IF aNeed_Lab = 1 THEN
        BEGIN
                GET Nurse OR Nurse_Tech
                WAIT T(2,8,25,1)
                CREATE 1 AS Lab_Sample TAKE ALL
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Lab_Sample
                Graphic 3
        END
IF aNeed_Resp = 1 THEN
        BEGIN
                GET Resp_Tech
                WAIT 3 MIN
                FREE Resp_Tech
                WAIT 20 MIN
                GET Resp_Tech
                WAIT 3 MIN
                FREE Resp_Tech
        END
                GET Nurse OR Nurse_Tech
                WAIT 5.5 MIN
                FREE ALL
                GET Doctor
                WAIT 5 MIN
                FREE Doctor
                GET Nurse
                WAIT N(2.66,2.24,1)
                FREE Nurse
```

```
            ROUTE 7
        END
ELSE
IF aPt_Type = 1 THEN
        BEGIN
            aNeed_Lab = BI(1,.61)
            aNeed_Rad = BI(1,.35)
            aNeed_Resp = BI(1,.20)
            aNeed_US = BI(1,.07)
            aNeed_CT = BI(1,.10)
            GET Nurse OR Nurse_Tech
            WAIT 10 MIN
            FREE ALL
IF aNeed_Rad = 1 THEN
        BEGIN
            GET Rad_Tech
            ROUTE 1
            Graphic 4
            MATCH aPt_ID
            JOIN 1 Patient
            Graphic 3
            FREE Rad_Tech
            MATCH aPt_ID
            JOIN 1 XRay_film
        END
IF aNeed_Lab = 1 THEN
        BEGIN
            GET Nurse OR Nurse_Tech
            WAIT T(2,8,25,1)
            CREATE 1 AS Lab_Sample TAKE ALL
            Graphic 4
            MATCH aPt_ID
            JOIN 1 Lab_Sample
            Graphic 3
        END
IF aNeed_Resp = 1 THEN
        BEGIN
```

```
                GET Resp_Tech
                WAIT 3 MIN
                FREE Resp_Tech
                WAIT 20 MIN
                GET Resp_Tech
                WAIT 3 MIN
                FREE Resp_Tech
        END
IF aNeed_US = 1 THEN
        BEGIN
                GET Rad_Tech
                ROUTE 3
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 US_result
        END
IF aNeed_CT = 1 THEN
        BEGIN
                GET Rad_Tech
                ROUTE 4
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 CT_result
        END
                GET Nurse OR Nurse_Tech
                WAIT 12.25 MIN
                FREE ALL
                GET Doctor
                WAIT 2 MIN
```

```
                FREE Doctor
                GET Nurse
                WAIT N(3.59,3.25,1)
                FREE Nurse
                ROUTE 7
        END
ELSE
IF aPt_Type = 2 THEN
        BEGIN
                aNeed_Lab = BI(1,.97)
                aNeed_Rad = BI(1,.90)
                aNeed_Resp = BI(1,.50)
                aNeed_US = BI(1,.07)
                aNeed_CT = BI(1,.20)
                GET Nurse OR Nurse_Tech
                WAIT 5 MIN
                FREE ALL
                GET Nurse
                WAIT 5 MIN
                FREE Nurse
IF aNeed_Rad = 1 THEN
        BEGIN
                GET Rad_Tech
                ROUTE 1
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 XRay_film
        END
IF aNeed_Lab = 1 THEN
        BEGIN
                GET Nurse OR Nurse_Tech
                WAIT T(2,8,25,1)
                CREATE 1 AS Lab_Sample TAKE ALL
```

```
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Lab_Sample
                Graphic 3
        END
IF aNeed_Resp = 1 THEN
        BEGIN
                GET Resp_Tech
                WAIT 3 MIN
                FREE Resp_Tech
                WAIT 20 MIN
                GET Resp_Tech
                WAIT 3 MIN
                FREE Resp_Tech
        END
IF aNeed_US = 1 THEN
        BEGIN
                GET Rad_Tech
                ROUTE 3
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 US_result
        END
IF aNeed_CT = 1 THEN
        BEGIN
                GET Rad_Tech
                ROUTE 4
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
```

```
                JOIN 1 CT_result
        END
                GET Nurse_Tech OR Nurse
                WAIT 11 MIN
                FREE ALL
                GET Nurse
                WAIT 11 MIN
                FREE Nurse
                GET Doctor
                WAIT 11 MIN
                FREE Doctor
                GET Nurse
                WAIT N(5.50,6.36,1)
                FREE Nurse
                ROUTE 7
END
END
ELSE
IF aNeedTrauma = 1 THEN
        BEGIN
                GRAPHIC 3
IF aPt_Type = 3 THEN
        BEGIN
                JOINTLY GET 1 Doctor, 100 AND (1 Nurse_Tech, 100 OR 1 Nurse, 100) AND 1 Register_Tech, 100
                WAIT T(0.5,7,10,1)
                INC aRegistered
                FREE Register_Tech
                WAIT 2 MIN
                FREE ALL
                aNeed_Rad = BI(1,.97)
                aNeed_Lab = BI(1,.94)
                aNeed_Resp = BI(1,.50)
                aNeed_US = BI(1,.03)
                aNeed_CT = BI(1,.20)
                aNeed_MRI = BI(1,.01)
                aNeed_NMed = BI(1,.001)
IF aNeed_Rad = 1 THEN
```

```
        BEGIN
                GET Rad_Tech
                ROUTE 1
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 XRay_film
        END
IF aNeed_Lab = 1 THEN
        BEGIN
                GET Nurse OR Nurse_Tech
                WAIT T(2,8,25,1)
                CREATE 1 AS Lab_Sample TAKE ALL
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Lab_Sample
                Graphic 3
        END
IF aNeed_Resp = 1 THEN
        BEGIN
                GET Resp_Tech
                WAIT 3 MIN
                FREE Resp_Tech
                WAIT 20 MIN
                GET Resp_Tech
                WAIT 3 MIN
                FREE Resp_Tech
        END
IF aNeed_US = 1 THEN
        BEGIN
                GET Rad_Tech
                ROUTE 3
                Graphic 4
                MATCH aPt_ID
```

```
            JOIN 1 Patient
            Graphic 3
            FREE Rad_Tech
            MATCH aPt_ID
            JOIN 1 US_result
      END
IF aNeed_CT = 1 THEN
      BEGIN
            GET Rad_Tech
            ROUTE 4
            Graphic 4
            MATCH aPt_ID
            JOIN 1 Patient
            Graphic 3
            FREE Rad_Tech
            MATCH aPt_ID
            JOIN 1 CT_result
      END
IF aNeed_MRI = 1 THEN
      BEGIN
            GET Rad_Tech
            ROUTE 5
            Graphic 4
            MATCH aPt_ID
            JOIN 1 Patient
            Graphic 3
            FREE Rad_Tech
            MATCH aPt_ID
            JOIN 1 MRI_result
      END
IF aNeed_NMed = 1 THEN
      BEGIN
            GET Rad_Tech
            ROUTE 6
            Graphic 4
            MATCH aPt_ID
            JOIN 1 Patient
```

```
            Graphic 3
            FREE Rad_Tech
            MATCH aPt_ID
            JOIN 1 NMed_result
      END
aNeed_Admit = BI(1,.33)
IF aNeed_Admit = 1 THEN
      BEGIN
            WAIT T(30,38,90,1)
            GET Nurse_Tech OR Nurse
            ROUTE 2
      END
ELSE
      BEGIN
            GET Nurse_Tech OR Nurse
            WAIT 11 MIN
            FREE ALL
            GET Nurse
            WAIT 11 MIN
            FREE Nurse
            GET Doctor
            WAIT 11 MIN
            FREE Doctor
            GET Nurse
            WAIT N(5.50,6.36,1)
            FREE Nurse
            ROUTE 7
      END
END
ELSE
IF aPt_Type = 2 AND aRegistered = 0 THEN
      BEGIN
            JOINTLY GET 1 Doctor, 100 AND (1 Nurse_Tech, 100 OR 1 Nurse, 100) AND 1 Register_Tech, 100
            WAIT T(0.5,7,10,1)
            INC aRegistered
            FREE Register_Tech
            WAIT 2 MIN
```

```
                FREE ALL
                aNeed_Rad = BI(1,.94)
                aNeed_Lab = BI(1,.97)
                aNeed_Resp = BI(1,.50)
                aNeed_US = BI(1,.10)
                aNeed_CT = BI(1,.20)
                aNeed_MRI = BI(1,.02)
IF aNeed_Rad = 1 THEN
        BEGIN
                GET Rad_Tech
                ROUTE 1
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 XRay_film
        END
IF aNeed_Lab = 1 THEN
        BEGIN
                GET Nurse OR Nurse_Tech
                WAIT T(2,8,25,1)
                CREATE 1 AS Lab_Sample TAKE ALL
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Lab_Sample
                Graphic 3
        END
IF aNeed_Resp = 1 THEN
        BEGIN
                GET Resp_Tech
                WAIT 3 MIN
                FREE Resp_Tech
                WAIT 20 MIN
                GET Resp_Tech
                WAIT 3 MIN
```

```
                FREE Resp_Tech
        END
IF aNeed_US = 1 THEN
        BEGIN
                GET Rad_Tech
                ROUTE 3
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 US_result
        END
IF aNeed_CT = 1 THEN
        BEGIN
                GET Rad_Tech
                ROUTE 4
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 CT_result
        END
IF aNeed_MRI = 1 THEN
        BEGIN
                GET Rad_Tech
                ROUTE 5
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 MRI_result
```

```
		END
	aNeed_Admit = BI(1,.294)
	IF aNeed_Admit = 1 THEN
		BEGIN
			WAIT T(30,38,90,1)
			GET Nurse_Tech OR Nurse
			ROUTE 2
		END
	ELSE
		BEGIN
			GET Nurse_Tech OR Nurse
			WAIT 11 MIN
			FREE ALL
			GET Nurse
			WAIT 11 MIN
			FREE Nurse
			GET Doctor
			WAIT 11 MIN
			FREE Doctor
			GET Nurse
			WAIT N(5.50,6.36,1)
			FREE Nurse
			ROUTE 7
		END
	END
	ELSE
	IF aPt_Type = 1 AND aRegistered = 0 THEN
		BEGIN
			JOINTLY GET 1 Doctor, 100 AND (1 Nurse_Tech, 100 OR 1 Nurse, 100) AND 1 Register_Tech, 100
			WAIT T(.5,7,10,1)
			INC aRegistered
			FREE Register_Tech
			WAIT 2 MIN
			FREE ALL
			aNeed_Rad = BI(1,.40)
			aNeed_Lab = BI(1,.61)
			aNeed_Resp = BI(1,.20)
```

```
                aNeed_US = BI(1,.10)
                aNeed_CT = BI(1,.15)
IF aNeed_Rad = 1 THEN
        BEGIN
                GET Rad_Tech
                ROUTE 1
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 XRay_film
        END
IF aNeed_Lab = 1 THEN
        BEGIN
                GET Nurse OR Nurse_Tech
                WAIT T(2,8,25,1)
                CREATE 1 AS Lab_Sample TAKE ALL
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Lab_Sample
                Graphic 3
        END
IF aNeed_Resp = 1 THEN
        BEGIN
                GET Resp_Tech
                WAIT 3 MIN
                FREE Resp_Tech
                WAIT 20 MIN
                GET Resp_Tech
                WAIT 3 MIN
                FREE Resp_Tech
        END
IF aNeed_US = 1 THEN
        BEGIN
                GET Rad_Tech
```

```
                ROUTE 3
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 US_result
        END
IF aNeed_CT = 1 THEN
        BEGIN
                GET Rad_Tech
                ROUTE 4
                Graphic 4
                MATCH aPt_ID
                JOIN 1 Patient
                Graphic 3
                FREE Rad_Tech
                MATCH aPt_ID
                JOIN 1 CT_result
        END
aNeed_Admit = BI(1,.096)
IF aNeed_Admit = 1 THEN
        BEGIN
                WAIT T(30,38,90,1)
                GET Nurse_Tech OR Nurse
                ROUTE 2
        END
ELSE
        BEGIN
                GET Nurse OR Nurse_Tech
                WAIT 12.25 MIN
                FREE ALL
                GET Doctor
                WAIT 2 MIN
                FREE Doctor
                GET Nurse
```

```
                WAIT N(3.59,3.25,1)
                FREE Nurse
                ROUTE 7
           END
      END
      END


                    1      Patient   Xrayroom_1    FIRST 1  MOVE WITH Rad_Tech
                           Patient   Xrayroom_2    FIRST    MOVE WITH Rad_Tech
                           Patient   Xrayroom_3    FIRST    MOVE WITH Rad_Tech
                           Patient   Xrayroom_4    FIRST    MOVE WITH Rad_Tech

                    2      Patient   Admission     FIRST 1  DEC vTrauma_Divert
                               MOVE FOR 15 MIN
                               FREE ALL
                    3      Patient   Ultrasound    FIRST 1  GRAPHIC 3
                               MOVE WITH Rad_Tech
                    4      Patient   CTscan        FIRST 1  GRAPHIC 3
                               MOVE WITH Rad_Tech
                    5      Patient   MRI           FIRST 1  GRAPHIC 3
                               MOVE WITH Rad_Tech
                    6      Patient   NucMed        FIRST 1  GRAPHIC 3
                               MOVE WITH Rad_Tech
                    7      Patient   Flee          FIRST 1  DEC vTrauma_Divert
                               GRAPHIC 1
                               MOVE ON Net1
```

Patient **Xrayroom_1 THRU Xrayroom_4**

```
   WAIT 2.+L(19.4, 10.3)
        CREATE 1 AS XRay_Film TAKE 1 Rad_Tech
```

```
GRAPHIC 4
GET Rad_Tech, 100
MATCH aPt_ID

    1  Patient  Treatmentroom_E1  JOIN 1  MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Treatmentroom_E2  JOIN    MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Treatmentroom_E3  JOIN    MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Treatmentroom_E4  JOIN    MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Treatmentroom_E6  JOIN    MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Treatmentroom_E7  JOIN    MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Treatmentroom_E8  JOIN    MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Treatmentroom_E9  JOIN    MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Treatmentroom_E10 JOIN    MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Treatmentroom_E11 JOIN    MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Treatmentroom_E12 JOIN    MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Treatmentroom_G1  JOIN    MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Treatmentroom_G2  JOIN    MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Traumaroom_T1     JOIN    MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Traumaroom_T2     JOIN    MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Traumaroom_T3     JOIN    MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Traumaroom_T4     JOIN    MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Traumaroom_T5     JOIN    MOVE WITH Rad_Tech, 100 THEN FREE
       Patient  Traumaroom_T6     JOIN    MOVE WITH Rad_Tech, 100 THEN FREE

Patient  Admission  LOG "LOS", aPt_Arrive_Time
           IF aPt_Type = 0 THEN LOG "LOG0", aPt_Arrive_Time
           IF aPt_Type = 1 THEN LOG "LOG1", aPt_Arrive_Time
           IF aPt_Type = 2 THEN LOG "LOG2", aPt_Arrive_Time
           IF aPt_Type = 3 THEN LOG "LOG3", aPt_Arrive_Time
           WAIT 30 MIN

    1  Patient  Flee  FIRST 1  GRAPHIC 1
                                 MOVE ON Net1

Patient  Ultrasound  WAIT T(30,35,60,1)
           CREATE 1 AS US_result
           GRAPHIC 4
```

```
MATCH aPt_ID
                     1     Patient   Treatmentroom_E6  JOIN 1  MOVE WITH Rad_Tech THEN FREE
                           Patient   Treatmentroom_E7  JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Treatmentroom_E8  JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Treatmentroom_E9  JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Treatmentroom_E10 JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Treatmentroom_E11 JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Treatmentroom_E12 JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Treatmentroom_G1  JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Treatmentroom_G2  JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Traumaroom_T1     JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Traumaroom_T2     JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Traumaroom_T3     JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Traumaroom_T4     JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Traumaroom_T5     JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Traumaroom_T6     JOIN    MOVE WITH Rad_Tech THEN FREE

Patient   CTscan    WAIT T(12,20,30,1)
          CREATE 1 AS CT_result
          GRAPHIC 4
          MATCH aPt_ID
                     1     Patient   Treatmentroom_E6  JOIN 1  MOVE WITH Rad_Tech THEN FREE
                           Patient   Treatmentroom_E7  JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Treatmentroom_E8  JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Treatmentroom_E9  JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Treatmentroom_E10 JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Treatmentroom_E11 JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Treatmentroom_E12 JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Treatmentroom_G1  JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Treatmentroom_G2  JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Traumaroom_T1     JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Traumaroom_T2     JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Traumaroom_T3     JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Traumaroom_T4     JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Traumaroom_T5     JOIN    MOVE WITH Rad_Tech THEN FREE
                           Patient   Traumaroom_T6     JOIN    MOVE WITH Rad_Tech THEN FREE
```

```
Patient   MRI       WAIT T(45,50,60,1)
                    CREATE 1 AS MRI_result
                    GRAPHIC 4
                    MATCH aPt_ID
                                    1   Patient   Treatmentroom_E6  JOIN 1  MOVE WITH Rad_Tech THEN FREE
                                        Patient   Treatmentroom_E7  JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Treatmentroom_E8  JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Treatmentroom_E9  JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Treatmentroom_E10 JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Treatmentroom_E11 JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Treatmentroom_E12 JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Treatmentroom_G1  JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Treatmentroom_G2  JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Traumaroom_T1     JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Traumaroom_T2     JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Traumaroom_T3     JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Traumaroom_T4     JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Traumaroom_T5     JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Traumaroom_T6     JOIN    MOVE WITH Rad_Tech THEN FREE

Patient   NucMed    WAIT T(60,90,120,1)
                    CREATE 1 AS NMed_result
                    GRAPHIC 4
                    MATCH aPt_ID
                                    1   Patient   Treatmentroom_E6  JOIN 1  MOVE WITH Rad_Tech THEN FREE
                                        Patient   Treatmentroom_E7  JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Treatmentroom_E8  JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Treatmentroom_E9  JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Treatmentroom_E10 JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Treatmentroom_E11 JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Treatmentroom_E12 JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Treatmentroom_G1  JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Treatmentroom_G2  JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Traumaroom_T1     JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Traumaroom_T2     JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Traumaroom_T3     JOIN    MOVE WITH Rad_Tech THEN FREE
                                        Patient   Traumaroom_T4     JOIN    MOVE WITH Rad_Tech THEN FREE
```

Patient Traumaroom_T5 JOIN MOVE WITH Rad_Tech THEN FREE
Patient Traumaroom_T6 JOIN MOVE WITH Rad_Tech THEN FREE

Patient Flee GRAPHIC 1
IF aNeed_Admit = 0 THEN LOG "LOS", aPt_Arrive_Time
IF aNeed_Admit = 0 AND aPt_Type = 0 THEN LOG "LOG0", aPt_Arrive_Time
IF aNeed_Admit = 0 AND aPt_Type = 1 THEN LOG "LOG1", aPt_Arrive_Time
IF aNeed_Admit = 0 AND aPt_Type = 2 THEN LOG "LOG2", aPt_Arrive_Time
IF aNeed_Admit = 0 AND aPt_Type = 3 THEN LOG "LOG3", aPt_Arrive_Time
DEC vPatients_Insystem

1 Patient EXIT FIRST 1

Patient EMS_Exit INC vNumber_Diverted

1 Patient EXIT FIRST 1

Lab_Sample Treatmentroom_E1 1 Lab_Sample Centrifuge_queue FIRST 1 MOVE WITH MECNurse, 200 THEN FREE

Lab_Sample Treatmentroom_E2 1 Lab_Sample Centrifuge_queue FIRST 1 MOVE WITH MECNurse, 200 THEN FREE

Lab_Sample Treatmentroom_E3 1 Lab_Sample Centrifuge_queue FIRST 1 MOVE WITH MECNurse, 200 THEN FREE

Lab_Sample Treatmentroom_E4 1 Lab_Sample Centrifuge_queue FIRST 1 MOVE WITH MECNurse, 200 THEN FREE

Lab_Sample Treatmentroom_E6 1 Lab_Sample Centrifuge_queue FIRST 1 MOVE WITH Nurse OR Nurse_Tech THEN FREE

Lab_Sample Treatmentroom_E7 1 Lab_Sample Centrifuge_queue FIRST 1 MOVE WITH Nurse OR Nurse_Tech THEN FREE

Lab_Sample Treatmentroom_E8 1 Lab_Sample Centrifuge_queue FIRST 1 MOVE WITH Nurse OR Nurse_Tech THEN FREE

Lab_Sample Treatmentroom_E9 1 Lab_Sample Centrifuge_queue FIRST 1 MOVE WITH Nurse OR Nurse_Tech THEN FREE

Lab_Sample Treatmentroom_E10 1 Lab_Sample Centrifuge_queue FIRST 1 MOVE WITH Nurse OR Nurse_Tech THEN FREE

Lab_Sample Treatmentroom_E11 1 Lab_Sample Centrifuge_queue FIRST 1 MOVE WITH Nurse OR Nurse_Tech THEN FREE

```
Lab_Sample  Treatmentroom_E12        1          Lab_Sample  Centrifuge_queue  FIRST 1  MOVE WITH Nurse OR Nurse_Tech THEN FREE

Lab_Sample  Treatmentroom_G1         1          Lab_Sample  Centrifuge_queue  FIRST 1  MOVE WITH Nurse OR Nurse_Tech THEN FREE

Lab_Sample  Treatmentroom_G2         1          Lab_Sample  Centrifuge_queue  FIRST 1  MOVE WITH Nurse OR Nurse_Tech THEN FREE

Lab_Sample  Traumaroom_T1            1          Lab_Sample  Centrifuge_queue  FIRST 1  MOVE WITH Nurse OR Nurse_Tech THEN FREE

Lab_Sample  Traumaroom_T2            1          Lab_Sample  Centrifuge_queue  FIRST 1  MOVE WITH Nurse OR Nurse_Tech THEN FREE

Lab_Sample  Traumaroom_T3            1          Lab_Sample  Centrifuge_queue  FIRST 1  MOVE WITH Nurse OR Nurse_Tech THEN FREE

Lab_Sample  Traumaroom_T4            1          Lab_Sample  Centrifuge_queue  FIRST 1  MOVE WITH Nurse OR Nurse_Tech THEN FREE

Lab_Sample  Traumaroom_T5            1          Lab_Sample  Centrifuge_queue  FIRST 1  MOVE WITH Nurse OR Nurse_Tech THEN FREE

Lab_Sample  Traumaroom_T6            1          Lab_Sample  Centrifuge_queue  FIRST 1  MOVE WITH Nurse OR Nurse_Tech THEN FREE

Lab_Sample  Centrifuge_queue
      GET Lab_Tech
                                     1      Lab_Sample  Centrifuge     FIRST 1  MOVE WITH Lab_Tech

Lab_Sample  Centrifuge      WAIT 2 MIN
             FREE Lab_Tech
             WAIT 41.2*(1./((1./U(0.5,0.5))-1.))**(1./2.69)
             GET Lab_Tech
             WAIT 1 MIN
             FREE Lab_Tech
             Route 1
                                     1      Lab_Sample  Lab_Results     FIRST 1  MOVE FOR .01 MIN

Lab_Sample  Lab_Results
      MATCH aPt_ID
                                            1      Lab_Sample  Treatmentroom_E1  JOIN 1  MOVE WITH MECPA, 200 THEN FREE
```

				Lab_Sample	Treatmentroom_E2	JOIN	MOVE WITH MECPA, 200 THEN FREE
				Lab_Sample	Treatmentroom_E3	JOIN	MOVE WITH MECPA, 200 THEN FREE
				Lab_Sample	Treatmentroom_E4	JOIN	MOVE WITH MECPA, 200 THEN FREE
				Lab_Sample	Treatmentroom_E6	JOIN	MOVE WITH Doctor THEN FREE
				Lab_Sample	Treatmentroom_E7	JOIN	MOVE WITH Doctor THEN FREE
				Lab_Sample	Treatmentroom_E8	JOIN	MOVE WITH Doctor THEN FREE
				Lab_Sample	Treatmentroom_E9	JOIN	MOVE WITH Doctor THEN FREE
				Lab_Sample	Treatmentroom_E10	JOIN	MOVE WITH Doctor THEN FREE
				Lab_Sample	Treatmentroom_E11	JOIN	MOVE WITH Doctor THEN FREE
				Lab_Sample	Treatmentroom_E12	JOIN	MOVE WITH Doctor THEN FREE
				Lab_Sample	Treatmentroom_G1	JOIN	MOVE WITH Doctor THEN FREE
				Lab_Sample	Treatmentroom_G2	JOIN	MOVE WITH Doctor THEN FREE
				Lab_Sample	Traumaroom_T1	JOIN	MOVE WITH Doctor THEN FREE
				Lab_Sample	Traumaroom_T2	JOIN	MOVE WITH Doctor THEN FREE
				Lab_Sample	Traumaroom_T3	JOIN	MOVE WITH Doctor THEN FREE
				Lab_Sample	Traumaroom_T4	JOIN	MOVE WITH Doctor THEN FREE
				Lab_Sample	Traumaroom_T5	JOIN	MOVE WITH Doctor THEN FREE
				Lab_Sample	Traumaroom_T6	JOIN	MOVE WITH Doctor THEN FREE
XRay_film	Xrayroom_1		1	XRay_film	XRayReview_room	FIRST 1	MOVE WITH Rad_Tech THEN FREE
XRay_film	Xrayroom_2		1	XRay_film	XRayReview_room	FIRST 1	MOVE WITH Rad_Tech THEN FREE
XRay_film	Xrayroom_3		1	XRay_film	XRayReview_room	FIRST 1	MOVE WITH Rad_Tech THEN FREE
XRay_film	Xrayroom_4		1	XRay_film	XRayReview_room	FIRST 1	MOVE WITH Rad_Tech THEN FREE
XRay_film	XRayReview_room	WAIT T(2,10,20,1)	1	XRay_film	XRay_Results	FIRST 1	MOVE WITH Rad_Tech, 100 THEN FREE
XRay_film	XRay_Results	MATCH aPt_ID	1	XRay_film	Treatmentroom_E1	JOIN 1	MOVE WITH MECPA, 200 THEN FREE
				XRay_film	Treatmentroom_E2	JOIN	MOVE WITH MECPA, 200 THEN FREE
				XRay_film	Treatmentroom_E3	JOIN	MOVE WITH MECPA, 200 THEN FREE
				XRay_film	Treatmentroom_E4	JOIN	MOVE WITH MECPA, 200 THEN FREE
				XRay_film	Treatmentroom_E6	JOIN	MOVE WITH Doctor THEN FREE

		XRay_film	Treatmentroom_E7	JOIN	MOVE WITH Doctor THEN FREE
		XRay_film	Treatmentroom_E8	JOIN	MOVE WITH Doctor THEN FREE
		XRay_film	Treatmentroom_E9	JOIN	MOVE WITH Doctor THEN FREE
		XRay_film	Treatmentroom_E10	JOIN	MOVE WITH Doctor THEN FREE
		XRay_film	Treatmentroom_E11	JOIN	MOVE WITH Doctor THEN FREE
		XRay_film	Treatmentroom_E12	JOIN	MOVE WITH Doctor THEN FREE
		XRay_film	Treatmentroom_G1	JOIN	MOVE WITH Doctor THEN FREE
		XRay_film	Treatmentroom_G2	JOIN	MOVE WITH Doctor THEN FREE
		XRay_film	Traumaroom_T1	JOIN	MOVE WITH Doctor THEN FREE
		XRay_film	Traumaroom_T2	JOIN	MOVE WITH Doctor THEN FREE
		XRay_film	Traumaroom_T3	JOIN	MOVE WITH Doctor THEN FREE
		XRay_film	Traumaroom_T4	JOIN	MOVE WITH Doctor THEN FREE
		XRay_film	Traumaroom_T5	JOIN	MOVE WITH Doctor THEN FREE
		XRay_film	Traumaroom_T6	JOIN	MOVE WITH Doctor THEN FREE
US_result Ultrasound					
	1	US_result	XRay_Results	FIRST 1	MOVE FOR 2 MIN
US_result XRay_Results MATCH aPt_ID					
	1	US_result	Treatmentroom_E6	JOIN 1	MOVE WITH Doctor THEN FREE
		US_result	Treatmentroom_E7	JOIN	MOVE WITH Doctor THEN FREE
		US_result	Treatmentroom_E8	JOIN	MOVE WITH Doctor THEN FREE
		US_result	Treatmentroom_E9	JOIN	MOVE WITH Doctor THEN FREE
		US_result	Treatmentroom_E10	JOIN	MOVE WITH Doctor THEN FREE
		US_result	Treatmentroom_E11	JOIN	MOVE WITH Doctor THEN FREE
		US_result	Treatmentroom_E12	JOIN	MOVE WITH Doctor THEN FREE
		US_result	Treatmentroom_G1	JOIN	MOVE WITH Doctor THEN FREE
		US_result	Treatmentroom_G2	JOIN	MOVE WITH Doctor THEN FREE
		US_result	Traumaroom_T1	JOIN	MOVE WITH Doctor THEN FREE
		US_result	Traumaroom_T2	JOIN	MOVE WITH Doctor THEN FREE
		US_result	Traumaroom_T3	JOIN	MOVE WITH Doctor THEN FREE
		US_result	Traumaroom_T4	JOIN	MOVE WITH Doctor THEN FREE
		US_result	Traumaroom_T5	JOIN	MOVE WITH Doctor THEN FREE
		US_result	Traumaroom_T6	JOIN	MOVE WITH Doctor THEN FREE
CT_result CTscan	1	CT_result	XRay_Results	FIRST 1	MOVE FOR 2 MIN

CT_result XRay_Results MATCH aPt_ID	1	CT_result	Treatmentroom_E6	JOIN 1	MOVE WITH Doctor THEN FREE
		CT_result	Treatmentroom_E7	JOIN	MOVE WITH Doctor THEN FREE
		CT_result	Treatmentroom_E8	JOIN	MOVE WITH Doctor THEN FREE
		CT_result	Treatmentroom_E9	JOIN	MOVE WITH Doctor THEN FREE
		CT_result	Treatmentroom_E10	JOIN	MOVE WITH Doctor THEN FREE
		CT_result	Treatmentroom_E11	JOIN	MOVE WITH Doctor THEN FREE
		CT_result	Treatmentroom_E12	JOIN	MOVE WITH Doctor THEN FREE
		CT_result	Treatmentroom_G1	JOIN	MOVE WITH Doctor THEN FREE
		CT_result	Treatmentroom_G2	JOIN	MOVE WITH Doctor THEN FREE
		CT_result	Traumaroom_T1	JOIN	MOVE WITH Doctor THEN FREE
		CT_result	Traumaroom_T2	JOIN	MOVE WITH Doctor THEN FREE
		CT_result	Traumaroom_T3	JOIN	MOVE WITH Doctor THEN FREE
		CT_result	Traumaroom_T4	JOIN	MOVE WITH Doctor THEN FREE
		CT_result	Traumaroom_T5	JOIN	MOVE WITH Doctor THEN FREE
		CT_result	Traumaroom_T6	JOIN	MOVE WITH Doctor THEN FREE
MRI_result MRI	1	MRI_result	XRay_Results	FIRST 1	MOVE FOR 2 MIN
MRI_result XRay_Results MATCH aPt_ID	1	MRI_result	Treatmentroom_E6	JOIN 1	MOVE WITH Doctor THEN FREE
		MRI_result	Treatmentroom_E7	JOIN	MOVE WITH Doctor THEN FREE
		MRI_result	Treatmentroom_E8	JOIN	MOVE WITH Doctor THEN FREE
		MRI_result	Treatmentroom_E9	JOIN	MOVE WITH Doctor THEN FREE
		MRI_result	Treatmentroom_E10	JOIN	MOVE WITH Doctor THEN FREE
		MRI_result	Treatmentroom_E11	JOIN	MOVE WITH Doctor THEN FREE
		MRI_result	Treatmentroom_E12	JOIN	MOVE WITH Doctor THEN FREE
		MRI_result	Treatmentroom_G1	JOIN	MOVE WITH Doctor THEN FREE
		MRI_result	Treatmentroom_G2	JOIN	MOVE WITH Doctor THEN FREE
		MRI_result	Traumaroom_T1	JOIN	MOVE WITH Doctor THEN FREE
		MRI_result	Traumaroom_T2	JOIN	MOVE WITH Doctor THEN FREE
		MRI_result	Traumaroom_T3	JOIN	MOVE WITH Doctor THEN FREE
		MRI_result	Traumaroom_T4	JOIN	MOVE WITH Doctor THEN FREE
		MRI_result	Traumaroom_T5	JOIN	MOVE WITH Doctor THEN FREE
		MRI_result	Traumaroom_T6	JOIN	MOVE WITH Doctor THEN FREE

```
NMed_result NucMed              1     NMed_result XRay_Results     FIRST 1  MOVE FOR 2 MIN

NMed_result XRay_Results
        MATCH aPt_ID            1     NMed_result Treatmentroom_E6  JOIN 1  MOVE WITH Doctor THEN FREE
                                      NMed_result Treatmentroom_E7  JOIN    MOVE WITH Doctor THEN FREE
                                      NMed_result Treatmentroom_E8  JOIN    MOVE WITH Doctor THEN FREE
                                      NMed_result Treatmentroom_E9  JOIN    MOVE WITH Doctor THEN FREE
                                      NMed_result Treatmentroom_E10 JOIN    MOVE WITH Doctor THEN FREE
                                      NMed_result Treatmentroom_E11 JOIN    MOVE WITH Doctor THEN FREE
                                      NMed_result Treatmentroom_E12 JOIN    MOVE WITH Doctor THEN FREE
                                      NMed_result Treatmentroom_G1  JOIN    MOVE WITH Doctor THEN FREE
                                      NMed_result Treatmentroom_G2  JOIN    MOVE WITH Doctor THEN FREE
                                      NMed_result Traumaroom_T1     JOIN    MOVE WITH Doctor THEN FREE
                                      NMed_result Traumaroom_T2     JOIN    MOVE WITH Doctor THEN FREE
                                      NMed_result Traumaroom_T3     JOIN    MOVE WITH Doctor THEN FREE
                                      NMed_result Traumaroom_T4     JOIN    MOVE WITH Doctor THEN FREE
                                      NMed_result Traumaroom_T5     JOIN    MOVE WITH Doctor THEN FREE
                                      NMed_result Traumaroom_T6     JOIN    MOVE WITH Doctor THEN FREE

Phone_call  Phone_Queue         1     Phone_call  Phone       FIRST 1

Phone_call  Phone        GET ER_Clerk OR Nurse_Tech OR Nurse OR Doctor
              WAIT T(.17,2,7,1)MIN
              FREE ALL
                                1     Phone_call  EXIT        FIRST 1


**************************************************************************
*                    Arrivals                    *
**************************************************************************

 Entity   Location   Qty Each                        First Time Occurrences Frequency  Logic
 -------- ---------- ------------------------------- ---------- ----------- ---------- ------------
 Patient  Entrance   N(72.16,11.18); NonEMSArrivals      0         INF        24 HR
 Patient  EMS_Ent    N(13.03,4.62); EMSArrivals                0          INF        24 HR
```

```
Phone_call Phone_Queue T(200,250,320,1); PhonecallArrivals        0        INF        24 HR

********************************************************************************
*                       Shift Assignments                    *
********************************************************************************

Locations... Resources...   Shift Files...                   Priorities... Disable Logic...
------------ --------------- ------------------------------------ ------------- ------- ------------------
          MECNurse       C:\Program Files\MedModel\Shifts\CTMC 0,99,99,99    No
          MECPA

          ER_Clerk:1      C:\Program Files\MedModel\Shifts\ERCl 0,99,99,99    No

          Register_Tech:1 C:\Program Files\MedModel\Shifts\Regi 0,99,99,99    No

          Triage_Tech:1   C:\Program Files\MedModel\Shifts\Tria 0,99,99,99    No

          Nurse_Tech:1    C:\Program Files\MedModel\Shifts\Nurs 0,99,99,99    No

          Rad_Tech:2      C:\Program Files\MedModel\Shifts\RadT 0,99,99,99    No

          Rad_Tech:3      C:\Program Files\MedModel\Shifts\RadT 0,99,99,99    No

          Rad_Tech:4      C:\Program Files\MedModel\Shifts\RadT 0,99,99,99    No


********************************************************************************
*                          Attributes                    *
********************************************************************************

 ID            Type         Classification
 --------------- ------------ --------------
#
#Describes patient type 0=MEC, 1=Brown, 2=Yellow, 3=Red
 aPt_Type        Integer      Entity
```

```
#
#Binomial Dist if patient needs Lab
 aNeed_Lab      Integer     Entity
#
#Binomial Dist if patient needs Rad
 aNeed_Rad      Integer     Entity
#
#Binomial Dist if Patient needs Resp
 aNeed_Resp     Integer     Entity
#
#Unique Identifier for patient
 aPt_ID         Integer     Entity
#
#Binomial Dist if patient needs to be admitted to hospital
 aNeed_Admit    Integer     Entity
#
#Binomial Dist if patient needs Nuclear Medicine
 aNeed_NMed     Integer     Entity
#
#Binomial Dist if patient needs UltraSound
 aNeed_US       Integer     Entity
#
#Binomial Dist if patient needs Computed Tomography
 aNeed_CT       Integer     Entity
#
#Binomial Dist if patient needs Magnetic Resonance Imaging
 aNeed_MRI      Integer     Entity
#
#0 if patient not registered, 1 if registered
 aRegistered    Integer     Entity
#
#0 if aPt_Type = 2 and needs no Trauma care. Else = 1
 aNeedTrauma    Integer     Entity
#
#Attribute/variable that stores the patients time of arrival in system clock
 minutes.
 aPt_Arrive_Time Integer    Entity
```

```
*******************************************************************************
*                    Variables (global)                    *
*******************************************************************************

 ID              Type        Initial value Stats
 ------------------ ------------ ------------- -----------

#Unique ID for each patient
 vPt_ID          Integer     0          Time Series

#Variable to convert/hold the simulation clock time in minutes
 vClock_min       Integer    0          Time Series

#Variable to hold/calculate the daily clock time in military hours
 vClock_hour      Integer    0          Time Series

#Variable to hold/calculate the simulation days expired
 vClock_day       Integer    0          Time Series

#Variable to track # of patients in system
 vPatients_Insystem Integer    0          Time Series

#Variable to determine diversion status of Trauma rooms (full = 10)
 vTrauma_Divert    Integer    0          Time Series

#Variable to count the number of patients diverted
 vNumber_Diverted  Integer    0          Time Series
```

```
*****************************************************************************
*                          Subroutines                          *
*****************************************************************************

 ID                    Type       Parameter  Type       Logic
 -------------------------- ------------- ----------- ------------ ------------------
 Simulation_Clockconversion None                             WHILE 1=1 DO
                                             BEGIN
                                                 WAIT 1 MIN
                                                 INC vClock_min
                                                 IF vClock_min = 60 THEN
                                                         BEGIN
                                                                 INC vClock_hour
                                                                 vClock_min = 0
                                                         END
                                                 IF vClock_hour = 24 THEN
                                                         BEGIN
                                                                 INC vClock_day
                                                                 vClock_hour = 0
                                                         END
                                             END
```

```
**************************************************************************
*                         Arrival Cycles                         *
**************************************************************************
 ID              Qty / %    Cumulative   Time (Hours) Value
 ---------------- ------------ ------------ ------------ ------------
 NonEMSArrivals   Percent     No
                                3          6.3
                                6          3.8
                                9          8.7
                                12          14.8
                                15          15.9
                                18          17.7
                                21          19.9
                                24          12.9
 EMSArrivals      Percent     No
                                3          10.4
                                6          7.4
                                9          7.9
                                12          13.1
                                15          15.8
                                18          13.9
                                21          18.4
                                24          13.1
 PhonecallArrivals Percent     No
                                3          4
                                6          6
                                9          10
                                12          10
                                15          10
                                18          25
                                21          25
                                24          10
```

```
*******************************************************************************
*                    Table Functions                    *
*******************************************************************************

ID         Independent Value Dependent Value
---------- ----------------- ---------------
Fun1

*******************************************************************************
*                    User Distributions                    *
*******************************************************************************

ID          Type         Cumulative   Percentage   Value
------------ ------------ ------------ ------------ ------------
dPt_Dist    Discrete     No
                                       47          0
                                       42          1
                                       11          2
                                       0           3
dEMSPt_Dist Discrete     No
                                       0           0
                                       59          1
                                       38          2
                                       3           3
```

****
*   External Files   *
****

ID	Type	File Name	Prompt
(null)	Shift	C:\Program Files\MedModel\Shifts\CTMCMEC2.sft	
(null)	Shift	C:\Program Files\MedModel\Shifts\ERClerk.sft	
(null)	Shift	C:\Program Files\MedModel\Shifts\RegisterTech.sft	
(null)	Shift	C:\Program Files\MedModel\Shifts\TriageTech.sft	
(null)	Shift	C:\Program Files\MedModel\Shifts\NurseTech.sft	
(null)	Shift	C:\Program Files\MedModel\Shifts\RadTechUnit2.sft	
(null)	Shift	C:\Program Files\MedModel\Shifts\RadTechUnit3.sft	
(null)	Shift	C:\Program Files\MedModel\Shifts\RadTechUnit4.sft	

APPENDIX D

MedModel Computer Simulation Program Input

Daily Arrival Frequency Main Entrance	Mean	SD
Normally Distributed	72.16	11.18

Daily Arrival Frequency. EMS Entrance	Mean	SD
Normally Distributed	13.03	4.62

Daily Arrival Frequency. Phone Calls	Minimum	Most Likely	Maximum
Triangular Distribution	200	250	320

Patient Type Main Entrance	Percentage
MEC "0"	47
Low	42
Medium	11
High	0

Note: 67% of Medium acuity treated as "trauma" patients.
100% of High acuity treated as "trauma" patients

Patient Type EMS Entrance	Percentage
MEC "0"	0
Low	59
Medium	38
High	3

Arrival Cycle. Non-EMS Time Block	Percentage
0 - 3 AM	6.3
3 - 6 AM	3.8
6 - 9 AM	8.7
9 - 12 AM	14.8
12 - 3 PM	15.9
3 - 6 PM	17.7
6 - 9 PM	19.9
9 - 12 PM	12.9

Arrival Cycle: EMS Time Block	Percentage
0 - 3 AM	10 4
3 - 6 AM	7 4
6 - 9 AM	7.9
9 - 12 AM	13.1
12 - 3 PM	15.8
3 - 6 PM	13.9
6 - 9 PM	18.4
9 - 12 PM	13.1

Arrival Cycle: Phone Calls Time Block	Percentage
0 - 3 AM	4
3 - 6 AM	6
6 - 9 AM	10
9 - 12 AM	10
12 - 3 PM	10
3 - 6 PM	25
6 - 9 PM	25
9 - 12 PM	10

Phone Call Distribution	Minimum	Most Likely	Maximum
Triangular Distribution	0.17	2	7

Triage Distribution	Minimum	Most Likely	Maximum
Triangular Distribution	2	3.03	17.8

Registration Distribution	Minimum	Shape value	Shape value	Scale value
Pearson 6 Distribution	1	5 02	14 8	21.9

X-Ray Distribution	Minimum	Mean	SD
LogNormal	2	19.4	10.3

X-Ray Review	Minimum	Most Likely	Maximum
Triangular Distribution	2	10	20

Nuclear Medicine	Minimum	Most Likely	Maximum
Triangular Distribution	60	90	120

MRI	Minimum	Most Likely	Maximum
Triangular Distribution	45	50	60

CT Scan	Minimum	Most Likely	Maximum
Triangular Distribution	12	20	30

UltraSound	Minimum	Most Likely	Maximum
Triangular Distribution	30	35	60

LAB Sample Draw	Minimum	Most Likely	Maximum
Triangular Distribution	2	8	25

LAB TAT	Minimum	Shape	Scale
LogLogistic	0	2 69	41.2

Respitory Therapy Treatment	Time for procedure
Initial treatment	3 minutes
Wait	20 minutes
Complete treatement	3 minutes

Patient Disposition process	Mean	SD
Normally Distributed	2.66	2 24

Patient Admission
15 minutes

Patient Pre-Admission Process "Bed-Ahead"	Minimum	Most Likely	Maximum
Triangular Distribution	30	38	90

	Percentage of patients receiving Procedure/Treatment by Type						
Trauma Rooms Patient Acuity Type	% Radiology	% Lab	% Resp	% US	%CT	%MRI	%NucMed
Low	40	61	20	10	15	0	0
Medium	94	97	50	10	20	2	0
High	97	94	50	3	20	1	0.1

	Percentage of patients receiving Procedure/Treatment by Type						
MEC Rooms	% Radiology	% Lab	% Resp	% US	%CT	%MRI	%NucMed
MEC "0"	45	12.5	8.5	0	0	0	0

Trauma Rooms Patient Acuity Type	Percentage of patients receiving Procedure/Treatment by Type						
	% Radiology	% Lab	% Resp	% US	%CT	%MRI	%NucMed
MEC "0"	45	12.5	8.5	0	0	0	0
Low	35	61	20	7	10	0	0
Medium	90	97	50	7	20	0	0
High	97	94	50	3	20	1	0 1

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Lance L. Roberts was born in Oceanside, California. He and his two brothers were raised in Wisconsin by his parents Patricia Ann Roberts and Tom Vernon Roberts. After completing his work at Sun Prairie High School in Sun Prairie, Wisconsin, and Tuloso-Midway High School in Corpus Christi, Texas, he enrolled himself at Texas State University-San Marcos in 1983. He worked his way through college and received his Bachelor of Science from Texas State in 1989 graduating *cum laude*. His professional career began in the manufacturing industry while he finished his last year of undergraduate work at Texas State. He worked 13 years, in sundry technical and supervisory positions, at Butler Manufacturing Company in San Marcos, Texas, and at Applied Materials in Austin, Texas. His professional achievements include being certified as a Manufacturing Technologist by the Society of Manufacturing Engineers (SME) and receiving certification in Production and Inventory Control from the American Production and Inventory Control Society (APICS). In 2002, he entered the Graduate College of Texas State. He worked as a Graduate Instructional Assistant and Graduate Teaching Assistant, teaching undergraduate level Statistics for Health Professionals, while working towards his Master of Science degree. In addition to his teaching duties, he performed the statistical analyses for a Nursing Research Program grant at Brooke Army Medical Center in San Antonio, Texas. He was a student volunteer at the 2003 and 2004 Annual Healthcare Information and Management Systems Society (HIMSS) Conference and Exhibition. He presented his thesis as a case study to the San Antonio, Texas, chapter of the American Society of Quality, the Central Texas Medical Center Leadership Council, and the Texas State College of Health Professionals Research Forum in the spring of 2004. His academic excellence, research work, teaching skills, and volunteer work earned him the Outstanding Health Services Research Student of the year award in the spring of 2004.

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