Securing the Safety Net: Applying Manufacturing Systems Methods Towards Understanding and Redesigning a Hospital Emergency Department

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Abstract

Emergency Departments have been referred to as the “Safety Net” of our Healthcare system. This is because of their ability to catch all patients who would otherwise slip through the system, due to lack of funds, insurance, time, transportation and knowledge, etc. Because of this, as demand for health treatment increases, the occurrence of crowding in our nation’s emergency departments is also increasing. At the same time hospitals are being expected to perform more, with lower funding.

Observation of a hospital emergency department yields similarities between the emergency department and a manufacturing system. This is not completely a new concept, yet there have been barriers towards adopting manufacturing system practices into healthcare systems due to differences in culture, economics, politics, and the nature of the system itself.

The focus of this thesis is to select manufacturing systems methods and apply them to an emergency department. This application is done with an understanding of the fundamental differences between the two systems. The first applied method is Axiomatic Design, a system design method that clearly maps out the functional requirements of a system to design solutions more efficiently. Upon applying Axiomatic Design to show that it can be used to discover and describe problems in an Emergency Department, the specific problem of patient flow is selected. Discrete Event Simulation is used in order to analyze patient flow in the Emergency Department. This results in actionable changes in the operations of an emergency department fast track. One significant actionable change is the creation of a new index for assigning patients a level based on their expected time in the Emergency Room to be used in conjunction with the current index which is based on acuity level.

The purpose of this exercise is to show that manufacturing methods can be applied in an emergency department/healthcare system while taking the differences between the two systems into account.

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Acknowledgment

To begin, I would like to thank the directors of the Park Center for Complex Systems: Professor Taesik Lee, Professor Sang Gook Kim, and President Nam Suh. President Suh had a brilliant vision that the field of healthcare could use the creative minds of the Park Center and his commitment led to an interesting and life altering research experience.

In line with President Suh’s vision, Prof. Lee took me into his research group. Prof. Lee, Erik Kolb, and I, set out as three engineers set out to perform meaningful research in a field we knew nothing about, but quickly learned a great deal. We learned far more than just healthcare though, we learned about applying engineering, design, manufacturing and ourselves in ways we had not considered before. We grew as an ideally functional research group and I will be forever thankful to the help and knowledge that was given to me. Even from afar we remain committed to our work together and to each other.

When Prof. Lee, decided to pursue new opportunities and Erik returned home, the group was gone, but my support did not end. Prof. Kim took on the reigns of the project and provided new outlooks and suggestions. He was patient with me as I adjusted to the changes in group dynamic and always respectful of me and my ideas. Prof. Kim has been an excellent advisor and I will always be grateful for the knowledge and support that he has generously provided.

I would like to express my very deep thanks to the staff at Newton-Wellesley hospital: Dr. Jellinek, Dr. Lemons, Elaine Bridge, Rob Swann, Patricia Miranda, Tanya Goldman, Pam Cormier, and the entire Emergency Department Staff. Thanks to the open minds and doors at Newton-Wellesley, we had an excellent working relationship, which made our project as pleasant as one could ever hope.

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Finally of course, I would like to thank my family; my Parents Fred and Jean Peck and my brothers Ron and Ethan, for their unwavering support as I continue my academic pursuits.

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List of Acronyms

DES - Discrete Event Simulation
DP - Design Parameter
ED - Emergency Department
ED^3 - Emergency Department Design Decomposition
ER - Emergency Room
EMS - Emergency Medical Services
ESI – Emergency Severity Index
FR - Functional Requirement
FT - Fast Track
LWBS - Left Without Being Seen
PCCS - Park Center for Complex Systems
PI – Park Index
MIT - Massachusetts Institute of Technology

Disclaimer

Many of the graphics and concepts in this thesis have been submitted in a final report to our partner hospital or for journal publication in "Health Care Management Science." These sections were written collaboratively by members of the PCCS: Dr. Taesik Lee, Erik Kolb, Dr. Sang-Gook Kim and Jordan Peck

1 Introduction

1.1 Motivation/Goal

Hospitals have gained the role of being the backbone of our healthcare system. The Emergency Department (ED) serves as the primary gateway for patients into a hospital, often accounting for the majority of patients that are admitted to a hospital. For those seeking care but lacking transportation and/or funds, EDs often act as the only option for receiving medical attention. This tendency for EDs to be the last resort for treatment has earned them the position as the "safety net" for the health care system [Asplin 2003]. EDs will take a patient around the clock, making them convenient for any patient's schedule. EDs take any patient despite their level of insurance. There are also ambulance services that can bring patients to the ED, making it accessible to those who have no other transportation.

As the population of the United States continues to age, the demand for hospital services increases. Meanwhile, due to budget constraints, hospitals are required to accomplish more, while using fewer resources. This general trend applies to EDs as well. Indeed, between 1994 and 2004, the amount of ED visits increased from 93.4 million to 110.2 million visits annually. Yet while the number of visits was increasing, the number of operating EDs in the United States decreased [McCaig 2004].

With this increasing patient visits to ED ratio, crowding in the ED has become more serious than ever. There have not been many detailed studies about the effects of crowding. However clinicians and researches have reported that crowding can cause prolonged pain for patients, deterioration in patient condition as they wait to be seen, inconvenience, dissatisfaction, and stress and frustration for those who work in the ED [US GAO 2003].

Crowding is not a new problem, crowding has been a source of concern since the early 1990s [Andrulis 1991]. Despite the attention paid to ED crowding for many years, the problem continues, meaning that new methods of addressing crowding are called for. The goal of this thesis is to introduce methods used in manufacturing systems and engineering design to improve flow in the ED and reduce crowding.

1.2 Background

1.2.1 Crowding

Former studies have broken down the causes of ED crowding into three components: input, throughput, and output. Input deals with problems caused by demand patterns, throughput deals with issues of getting the patient through the ED such as inefficient processes or resource availability and demand imbalances, and output deals with the factors that prevent the ED from releasing its patients [Asplin 2003].

Studies have been performed which delve into the above causes of crowding in more detail and part of understanding these causes is finding what real time metrics can be used to indicate when crowding is occurring or will soon occur. The US General Accounting Office performed a study where it identified indicators of crowding. One of these indicators is the amount of time that an ED is on ambulance diversion status. Ambulance diversion is a status that the ED declares when it will no longer take ambulances due to crowding. The second indicator is the number of patients who have been stabilized in the ED and are awaiting acceptance and transfer to the main hospital, these patients are known as boarding patients. Finally crowded conditions can be recognized when there are patients Leaving Without Being Seen (LWBS), due to unwillingness to endure the long waits for care [US GAO 2003].

The boarding patient indicator is the only one of these indicators that is representative of a cause of ED crowding, whereas the others are measures of the symptoms. Boarding patients are primarily high acuity patients. That is because high acuity patients are more likely to need treatment beyond the ED. It is these patients who require the largest amount of resources and reduce the department’s effective capacity by remaining in the ED. It has been shown, using discrete event simulation, that the relationship between an ED and its associated Inpatient Unit (IU) can have a direct effect on ED crowding [Kolb 2007]. Other studies have also discussed the correlation between the volume of high acuity patients, lowered capacity, and ED crowding [US GAO 2003, Cowan 2005, CAEP 2001, CAEP 2007, ENA 2005, Mass Health Policy Forum 2001, Olshaker 2006, Rathlev 2007].

1.2.2 Past Approaches

The issue of hospital operations and management has been studied for many years. Since as early as the 1950's, mathematical models have been created in order to evaluate the decisions of staffing, capacity and patient admissions within hospitals [Preater 2002]. One mathematical method that has been used by many researchers is Queuing Theory. Although Queuing Theory was originally developed to work with a telephone system, it has been applied to many service industries. Application of queuing models has proven useful in deciding appropriate resource levels and scheduling in healthcare settings [Green 2006-1]. Queuing Theory has successfully been used to address issues of crowding in the ED by studying adjustments in provider staffing and using patients who LWBS as a metric to judge the efficacy of changes [Green 2006-2]. Although Queuing Theory has been used successfully in many applications, it operates on the assumption that the processes that occur during treatment are held constant and does not offer the flexibility to study process changes that is available with other methods.

One method that relies a great deal on process change is called Lean. Lean can be summarized as the removal of waste in the processes and practices of an organization by fully understanding the value that the organization provides and where it actually provides that value. In this way, those implementing Lean study the system before proposing a design rather than accepting current designs as correct. In the manufacturing context, Lean has been used on the level of individual processes up to focusing on the design of an entire organization [Womack 2003]. Some hospitals have implemented a detailed Lean approach to the entire enterprise [Miller 2005]. Interviews revealed that many hospital staff and administrators have become familiar with the concepts of Lean, only in the context of improving individual processes. In practice hospital staffs have begun to run Lean events where a group of practitioners will focus on one specific process and create an improved design. Other studies have shown the benefits of having staff constantly observing and redesigning [Spear 2005]. However, this approach has not yet been widely implemented.

Simulation has shown many benefits when used in manufacturing systems. Thanks to the development of computers, the utility of simulation in respect to very complex systems continues to grow [Banks 2005]. With this in mind, simulation has been applied to healthcare services in the past [Jun 1999]. Unlike Queuing Theory, simulation offers more control over specific operations within the model, however the cost of such control is a need for more information and detail when creating the model. Simulation is discussed more thoroughly in Chapter 3.

1.3 Research Question/Thesis Layout

From many of the studies on ED crowding that were discussed above, an understanding has developed that "the causes of crowding often originate outside of the emergency department. Therefore, crowding is considered a systems issue, which can be examined at department and institution levels as well as at local, regional, and national levels"[ENA 2005]. Thus, ED overcrowding needs to be looked at in the context of the system in which the ED resides. At the highest abstraction, causes of overcrowding may come from one or combinations of the following system components: incoming patient volume and profile, processes of treating patients in the ED, discharging patients out of the ED, ED operations, government regulations etc. All of these system components need to be looked at to truly understand the dynamics that lead to ED overcrowding. In this way the approaches of Queuing Theory may not be broad enough to incorporate an ED system's complexity, which plays a significant role in crowding [France 2006].

A system perspective is required to simplify the ED system by putting all system activities in the context of the actual functions that EDs need to satisfy in order to be successful. Although alleviating overcrowding is one of the most significant problems in EDs, there exist other goals and requirements such as ensuring patient safety, maintaining clinical quality, etc. In order to ensure that solving one problem does not aggravate another, while studying the problem of ED overcrowding, and any potential solution to address the problem, it is important to ensure that improvements are achieved at the system level, not at the localized level.

With the necessity of a systems approach in mind, this thesis seeks to prove that the combination of two systems evaluation methods that have historically been used in other applications such as mechanical design and management of manufacturing systems can be combined in order to successfully improve operations of an ED, as well as provide a methodology for reducing crowding and costs. The study begins in Chapter 2 with an introduction to Axiomatic Design

(AD), a design method that has been used in designing anything from simple machines to complex systems. AD is applied to the ED in order to discover areas for improvement. With the areas for improvement identified, Chapter 3 describes the use of a Discrete Event Simulation (DES) to create an ED model which can be used to study changes to the ED.

Chapter 4 is a case study, performed with the assistance of a partner hospital, to show the efficacy of the proposed methods in influencing high level operations and hospital policy. Finally Chapter 5 takes the suggestions found in Chapter 4 and re-applies the proposed methods once again, but on a more detailed level, in order to find a more detailed recommendation to maximize the improvements suggested in Chapter 5.

1.4 Differences in Manufacturing and the Emergency Department

Before applying methods that have been used in manufacturing and mechanical design it is important to be clear about the differences between these fields and healthcare. Knowing these differences creates a clear boundary of what, if any, practices can not be applied or must be adapted. Knowing the differences between healthcare and manufacturing may even offer insights as to how to change healthcare to be more like manufacturing, to eliminate these differences and allow the application of proven practices. The following discussion is not exhaustive, but gives an idea of the extent of differences that do exist.

1.4.1 Input Levels and Properties

One primary difference between manufacturing systems and the Emergency Department is the nature of inputs to the system. To begin with, the input to a manufacturing system is generally an inanimate object, while in the emergency department it is a person. This distinction leads to many other differences. For example dealing with people leads to a lack of ability to control inputs to the system. By law, an ED cannot choose the types of patients it accepts. If a manufacturer has a product that loses money, then they can stop making it. If a type of patient costs the ED money the ED does not have the option of withholding treatment. This also means that the ED must always be prepared for any type of input. In a manufacturing situation, the strength and speed of tools can be pre-set to fit the materials they will be working. In an ED, all possible tools must be available at any time. This leads to difficulty with inventory and staffing.

Beyond picking the type of inputs, an ED can not control its rate of inputs. In practice methods have been developed in manufacturing systems that help to identify the optimal rate of input to maximize timely flow and delivery of products. An ED does not have this option. People come when they are hurt and the ED must accommodate, or the patient ends up waiting.

Although a manufacturing system may have changing demands for production volume and type over the course of its existence, an ED faces changing demands with season, time of day, day of week, etc. Time and season dependent changes in patient input are often predictable. However, the prediction is how the nature of the average injury will shift. The variety of injuries remains wide and difficult to predict, therefore an ED must remain prepared for anything at all times. These changes also require an ED to be more flexible with staffing and resources than a manufacturing system. An extreme case of variability in volume is if there is a demand surge due to a large accident, natural disaster, or pandemic. Such surges of inputs are not a concern for typical manufacturing systems.

A manufacturing system tends to control the properties of inputs for processing. System designers have chosen the kind of material upon which the system will work. The material's properties are known and the processing time can be predicted. This knowledge allows for the efficient management of materials as they flow through the system. In contrast, even after a patient has entered the ED system, it is sometimes not possible to accurately assess the "properties" of the patient, and therefore it is difficult to control and predict patient flow. In an attempt to identify the properties of a patient early on, EDs employ triage. Triage is used to sort patients based on their need for treatment. The most prominent triage method uses the Emergency Severity Index (ESI). ESI is comprised of 5 identification levels. If a patient requires immediate life-saving intervention, and therefore can not wait to be seen, then they are assigned an ESI level 1. If a patient is at a high risk, in severe pain, or requires many resources and has vital signs at dangerous levels, they are assigned ESI 2. Otherwise, the patient is assigned a level based on the amount of resources they will use; ESI 3 for many resources, ESI 4 for one resource, ESI 5 for no resources. The definition of a resource can be fairly wide. A resource can be lab work (blood or urine tests), X-rays, fluids, consultation, etc. Therefore a patient who only needs a urine test and a patient that only needs fluids, will each be given an ESI level 4 despite the fact that their complaint as well as treatment requirement is very different [Gilboy 2005].

Unlike many manufacturing systems, in an ED the patient's properties may deteriorate while in the system. This leads to an inability to stock or buffer store "products" until the system is ready to process them. This leads to a need to prioritize when patients are processed, instead of processing on a first come fist served basis. Also there is the potential that the properties of one patient can affect another patient, such as the danger of cross contamination especially in the case of air born diseases. This and other complications create the need for many safety precautions that lead to necessary inefficiencies in the ED.

Finally EDs have high pressure not to make mistakes. Manufacturing systems find ways to minimize their defect rates. This is because defects mean lost revenue for the system. In the ED system a defective result means the death or further injury of a patient, which can be very costly in both the economic and societal context.

1.4.2 Products are also Customers

Above it is suggested that patients have specific properties, like any material that is about to be manufactured. However, as human beings, patients have requirements beyond that of an inanimate object. Many of these requirements can be completely unrelated to their actual reason for coming to the ED. Since the patient is also a customer, it is important to ensure that these requirements are met.

Patients have requirements for comfort and security. Patients do not want to feel like they are in danger while in the ED. Patients also need to feel at ease in an ED, this creates demands for decoration, lighting, bed padding, etc. Although EDs are a high paced environment patients do not want to feel like they are being rushed or pushed out of the ED, on the other hand they don't want to feel like they are being delayed due to laxity of workers. A manufacturing product usually does not mind waiting or being stored and certainly can not tell the difference between a rushing worker and a slow one.

Worker personality is also a major factor in the ED. If a machinist has an abrasive personality but is excellent with a lathe, then they can still do their job without much difficulty. On the other hand if a nurse or doctor has a difficult personality, a patient will not be happy. Ideally the only requirement for being a good worker would be to get the job done well. However, a patient must also feel like they are being treated properly and providing proper treatment does not necessarily mean treating the patient properly.

Even two patients with the exact same complaint may have different time and treatment requirements. Elderly patients are slower to move and slower to respond, some patients are completely unresponsive. Also there is the possibility that the patient has psychological problems, in which case specialists and special safe rooms are required to work on the patient. Also some patients may have religious or traditional beliefs that cause them to reject certain kinds of treatment, which means alternative less effective/efficient options must be offered.

Privacy is one of the most prominent issues that arise from dealing with people. The need for patient privacy and confidentiality can cause inefficiencies that do not exist in a manufacturing system. Patients often want their own rooms even if their injury is of a low acuity. Also when registering or triaging a patient they need privacy to give personal information. This causes restrictions on how the ED is operated that lead to inefficient but necessary processes.

1.4.3 Employee Factor

The nature of the “product” is not the only thing that differentiates manufacturing systems from ED systems. The nature of a healthcare employee and “machine” are different form those that work in a manufacturing system.

When comparing the ED system to a manufacturing system, employees can in some ways be considered a machine and in other ways be compared to an operator. A doctor is assigned a patient, processes that patient and then the patient is moved on, this is similar to the activity of a machine. When the processing rate of a manufacturing system is too slow the system can acquire new machines to create an additional stream. Likewise it is the doctors in ED systems that limit the number of possible processing streams. Doctors are no ordinary machine though; they are complicated and very expensive. As with expensive machines in a manufacturing system, a high level utilization of doctors is important to hospital management to make the most out of a high capital expense. Doctors need to be able to identify and respond to a wide range of problems. This leads to necessity of hiring highly trained, highly expensive workers that may not be particularly good at any one particular activity. This means that doctors may offer the ability to respond to a variety of problems but not with the speed and accuracy of a specialized machine. This problem is difficult to overcome because having specialists for every complaint in the ED would be costly. This leads to the need to wait for specialists that work in the hospital to come to the ED as a consultant which can damage efficiency. The fact that doctors work on varieties of issues means that they do not simply process the same way every time, they must acquire different data and control different tools which makes the doctors their own machinists. Likewise, nurses act like operators of the whole system but also perform processing tasks.

Employees in an ED have a fundamentally different concern than those in a manufacturing system, in an ED lives are at stake. This difference in motivation creates a high pressure, fast paced environment. This means that ED employees must be able to work under a significant amount of stress that may not be as tangible in a manufacturing environment.

Because the ED environment is not one that most people would want to endure, and because it requires regular shift changes, there is a high demand for employees. This demand for employees is aggravated by the high demand for health treatment in general. The high demand for employees provides all healthcare workers a lot of mobility and bargaining power. This can have a direct affect on the ability of managers to make decisions that are in the best interest of efficiency. For example, one manager thought that having all of the nurses wear the same scrubs would make communication with patients more efficient. However when this was suggested the nurses felt that it damaged their ability to express themselves and the idea was rejected.

The problem with management in an ED goes even further. Unlike a manufacturing system, in an ED the management hierarchy is unclear. Often Doctor's work "in the hospital but not for it" which means that they do not directly answer to the management in the ED. Nurses on the other hand do directly answer to ED management but they must also meet the demands of doctors. On the higher scale the hospital may have a management group or corporate structure however it may also have a community board that exercises strong management influence. This lack of clear management power makes change very difficult to implement and also makes responsibility less clear [Glouberman 2001].

Finally a significant factor when trying to make improvements to flow in an ED when applying manufacturing systems methods is that time working on patient is a function of “product” as well as “machine.” In a manufacturing system the time it takes to machine a product of certain properties is generally constant. This is not the case in EDs; in an ED the complexity of the patient’s complaint is a factor but also the ability of a practitioner to respond to this complaint is important. Different practitioners have different styles of dealing with patients and this affects how long they may spend with the patient. This and other factors make it difficult to set a strict “takt” time for dealing with any patient. This concept is very important to note when drawing comparisons between manufacturing and healthcare in general. How to solve this complex problem and make healthcare systems more predictable and controllable should be the focus of future studies.

2 Axiomatic Design and the Emergency Department

2.1 The Emergency Department as a System

There are many ways to define a system. This definition can be different depending on the field of application and the background of the person making the definition. However based on the definitions of a system from many different sources, a system has been summarized as "an assemblage of interrelated components working together towards the accomplishment of certain goals" [Kim 2002].

There can be no question that the operation of an Emergency Department (ED) has many complexities. There are many different technologies being used, employees with different skills performing processes, government regulations, interaction with suppliers, patients, the rest of the hospital, Emergency Medical Services (EMS), health insurance, etc. All of these different entities are involved with the operation of the ED and they all work together towards the final goals of the ED, making the ED a complex system.

With the understanding that the ED is a complex system and is therefore working towards specific goals, it is necessary to understand those goals clearly on all levels in order to properly analyze and re-design the system. This chapter shows the potential for applying Axiomatic Design, a system design method that has been used in manufacturing systems, to better understand the ED system.

2.2 Application of Axiomatic Design

Axiomatic Design (AD) is a design tool that helps the user define and organize the goals of a system into a set of Functional Requirements (FR). These FRs can be decomposed into more FRs of greater detail, which can be decomposed further, and so on until a desired level of detail is reached. Having reached an understanding of the detailed requirements of the system, Design Parameters (DP) are chosen in order to satisfy each FR. Preferably a specific DP does not affect any FR other than that which it was assigned too, this is known as the independence axiom. If the independence axiom is satisfied, the complexity of the final design is significantly reduced and this is called an uncoupled design [Suh 2001].

The AD method leads to the creation of a functional decomposition that allows a designer to easily recognize when the independence axiom has not been satisfied, creating a coupling between a set of FRs and DPs. It is sometimes unavoidable to have these couplings, in which case it is desirable to re-think the system such that the order in which the DPs are chosen allows them to satisfy their FRs independent from their coupled sets; this is known as a decoupled design. If the system can not be re-thought in order to create a decoupled design, the design is considered coupled. Although a coupled design is very complex, AD remains useful because it clearly shows the nature of the coupling, allowing users of the design to predict the effects of one FR/DP set on another [Suh 2001].

Since an ED is so complex, it has a great deal of FRs on many levels. In normal practice, the more FRs there are, the more difficult it can be to satisfy the highest level requirements. As mentioned earlier AD simplifies how the system is viewed which allows the proper decisions to be made at all levels and resulting in an efficient design. In the following sections a functional decomposition of the ED is created, then, using AD tools, conclusions about the ED and potential areas for improvement are identified.

2.3 The Emergency Department Design Decomposition (ED^3)

The creation of a detailed design decomposition requires a strong working knowledge of the system. One must be familiar with the system at all levels in order to accurately identify the functional requirements at these levels. In order to achieve this working knowledge, researches from the Park Center for Complex Systems (PCCS) partnered with a suburban community hospital in the greater Boston area.

Through this connection, researchers spent time in the hospital ED observing the activities. Conversations were held with staff in order to ask them about their duties, their views of the ED and the processes that are regularly performed. There were also weekly scheduled meetings with ED management in order to discuss observations and ED official policy. Meetings were also held with nurses, physicians, and higher level hospital management. The result of all of these meetings and observation was an ability to create The Emergency Department Design Decomposition (ED^3), an AD decomposition of the ED System.

While building the ED^3, and generally when using AD, it is important to ensure that functions are stated in a 'solution neutral' fashion. Being solution neutral means that the objectives are clearly separated from the means of achieving them, in other words, the observed DPs do not define the FR. When analyzing a system by observing its current operations, it is easy to be biased by current design decisions. When making design decompositions a designer must be aware of the biased tendency and be careful to choose FRs based on what the system MUST achieve rather than what it IS achieving. If one is considering current operations when defining FRs, it is common to make compromises in the design to fit the bias based on observed solutions rather than searching for alternative solutions. In the ED^3, we force ourselves to overcome the biases caused by immersing ourselves in the system, by making sure our observations were focused on understanding why tasks are done, rather than what tasks are done.

As discussed earlier, using AD we start out with the high-level FRs of the system. These FRs tend to be fairly abstract. Then each FR is broken down into sub-FRs which have clearer meanings. Like the high level FRs, high level DPs are also abstract and broadly stated. Then as we get to lower levels the DPs become more tangible, and may be more readily recognizable as the observable activities and protocols being performed in the ED. If this decomposition were taken to the greatest detail possible, every single required action or process that is performed in the ED would be taken into account, from a doctor writing a prescription to cleaning staff mopping the floors. In order to maintain a high level view of the system and make changes that do not necessarily require clinical expertise, we decided to limit how deep the decomposition would go.

When dealing with complex engineering systems, a major problem is that the stakeholders involved with the system have different understandings of the system's actual objectives. By listing the FRs and DPs in a hierarchical fashion, low-level activities and decisions are related to high-level goals and objectives, giving a clear perspective. Figure 1 illustrates the decomposition process with the first two levels of decomposition from the ED^3. The complete list of FRs and DPs that comprise the ED^3 are located in Appendix A.

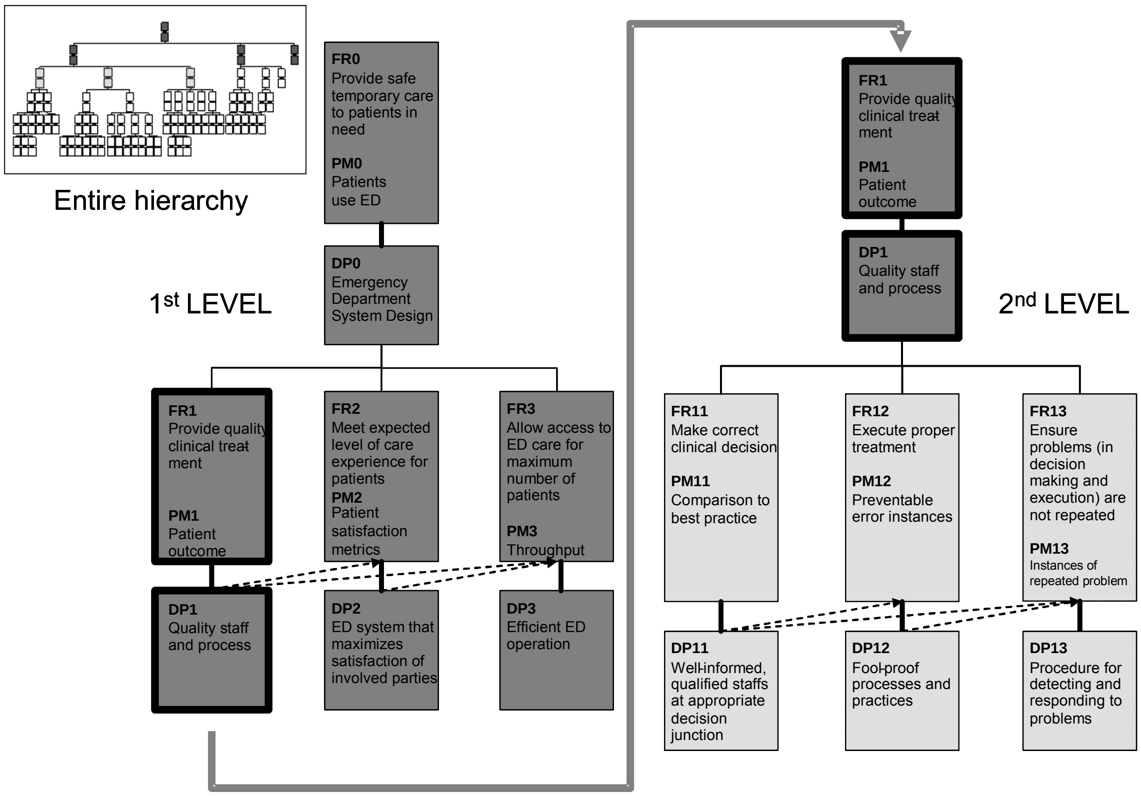


Figure 1: Decomposition structure of ED^3

Having a clear, visible reference to the system's objectives and functions facilitates communication among the stakeholders. Since the ED^3 clearly states objectives separate from the means and relates low-level activities and decisions to high-level goals it contributes to better communication and helps create mutual understanding and support from various stakeholders.

The ED^3 is a first attempt at decomposing the ED system and lists about 200 functional requirements. Figure 2 is a high level view of the ED^3. As can be seen from the figure the ED^3 has five top level requirements: quality, satisfaction, safety, access, and growth. Under each of these top level FRs are many more detailed levels of FR decomposition. Like many other design decompositions, the ED^3 is intended to be a living document that will evolve with future studies and new understandings.

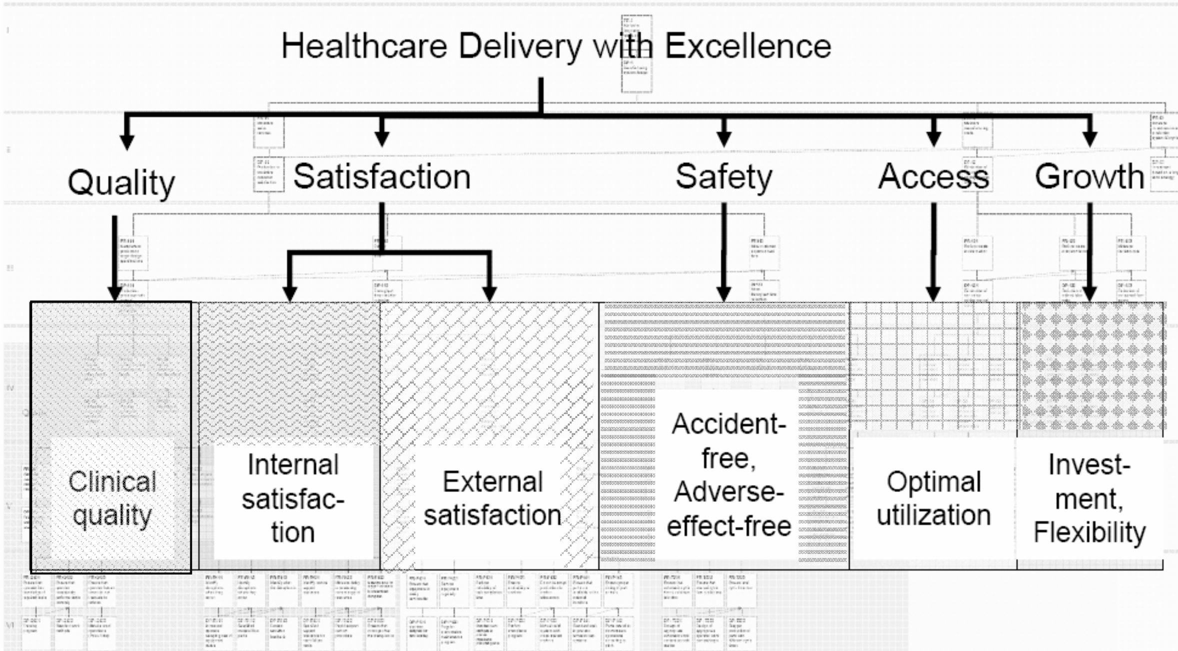


Figure 2: Emergency Department Design Decomposition (ED^3)

2.4 Lessons Learned from the ED^3

The ED^3 can be used to capture the interrelationships among the different elements of a system. As is called for by AD, for every FR, there is a matching DP to satisfy it. However, a DP may have unintended affects on other functions of the ED. For example, FR2.1.1 (Appendix A.3) calls for competitive salaries and compensation for workers as part of maintaining internal satisfaction. DP2.1.1 is to pay based on education and workload. A manager would like to accurately compensate staff in order to keep them satisfied, but high compensation can strain the budget, hindering other functions in the ED. These unintended effects, due to a coupled design as described earlier, often make it difficult to satisfy all of the objectives of the system and are clear targets for re-design focus.

In order to bring out the couplings in the ED^3, the decomposition was entered into a program used for AD called Acclaro® which was developed by Axiomatic Design Solutions Inc. This program makes it easy to organize the functional decomposition into a matrix form (Figure 3).

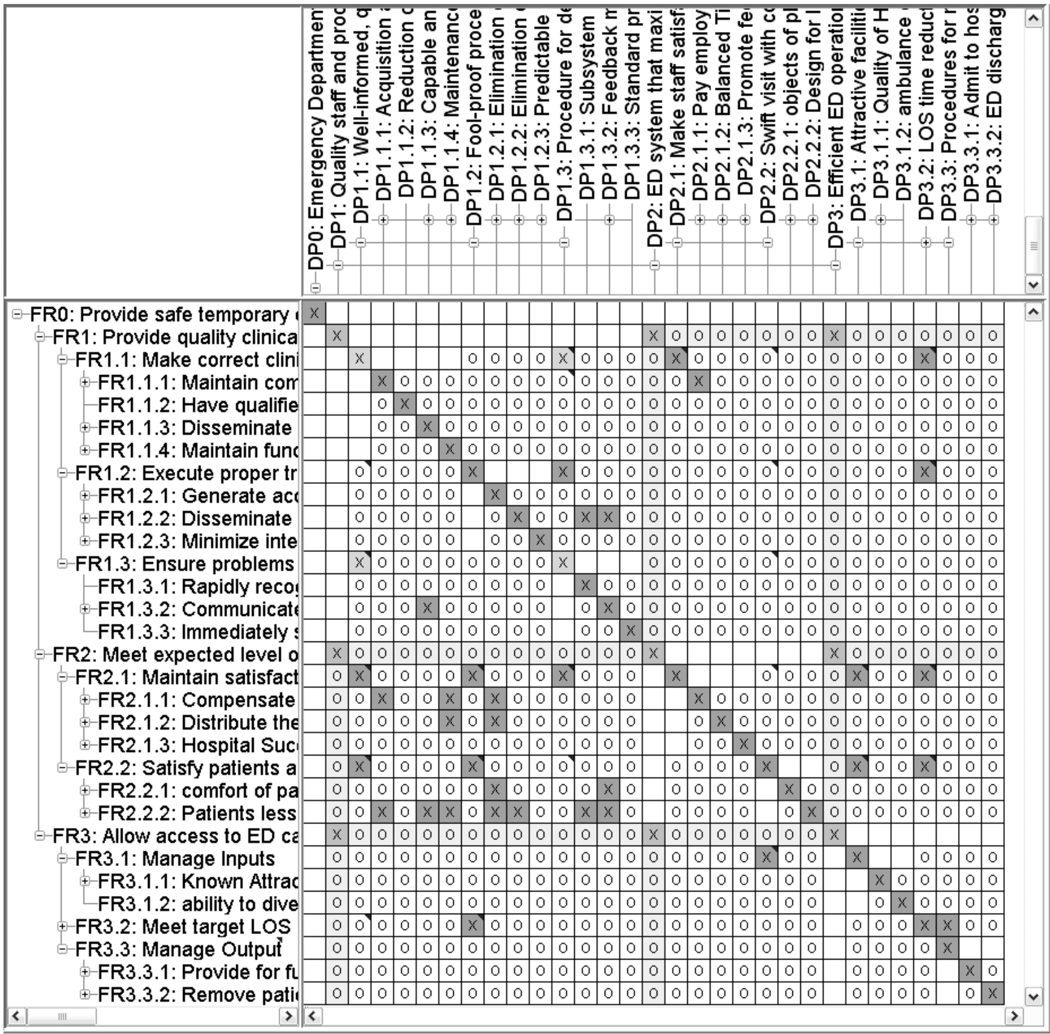


Figure 3: Matrix representation of the interrelationships between design parameters and functional requirements of the ED[3].

As seen in the above figure, the program creates a matrix with FRs on the vertical axis and DPs on the horizontal axis. Where an FR meets a DP there is a box that can have the value of '0', which means there is no relationship between the FR and DP, or 'X', which means there is a relationship. While in the matrix form, the user can analyze each FR/DP intersection, identify when a DP affects an FR, and denote that relationship with an X. Since each DP was created to satisfy one FR there is a diagonal line of Xs, if these were the only Xs then the design would be uncoupled. If the DP of one FR is tied to another FR, and the second FR's DP is tied to the original FR, then the pair is considered completely coupled and the program highlights the Xs.

The matrix is an effective view for identifying couplings and analyzing how much they will affect the system. However, when the matrix representation of the ED^3 is completely expanded, as in Figure 3 it can sometimes be overwhelming to pick out specific problems and couplings. Fortunately the matrix can be expanded or compressed to allow as much, or as little, detail as is desired. Figure 4 is the compressed version of the matrix only showing the highest level FRs and DPs.

	DP1: Quality, Staff and Processes	DP2: Satisfaction Providers	DP3: Safety Measures	DP4: Design for control of inputs and throughput	DP5: Research and Development
FR1: Quality clinical treatment through decisions and implementations	X	X	0	0	X
FR2: Maximized satisfaction for all involved parties	X	X	0	X	0
FR3: Parties are safe from receiving new injuries or diseases through the prevention or immediate response to health hazards	0	0	X	0	0
FR4: Immediate care is provided to all who need it	0	X	0	X	0
FR5: Ability to adopt new technologies and practices	X	0	0	0	X

Relationship

No Relationship

Figure 4: Compressed Matrix Representation of ED^3

As can be seen in the above figure, there are many high level couplings in the ED^3. Anyone who is familiar with the complexity of the ED system will not be surprised by this. Identifying all of the complex interactions and couplings is a worthwhile exercise. However, in the interest of identifying a specific problem and then working on it, steps were taken to simplify the ED^3 even more. Looking at Figure 4 it can be seen that FR3, Safety, is not coupled with any other FR, this is because safety measures and precautions can generally be taken without strongly affecting any of the other FRs; this means that it can be removed from the matrix. The ability to make this kind of a statement stems from a clear definition of each FR, any ambiguity allows designers too much room for interpretation and would cause couplings that may not exist in a clearer design. FR5 is coupled with FR1 because growth in terms of new knowledge and practices does affect quality; however it only does so in that it affects future quality as opposed to maximizing what currently exists in the ED, so since the focus of this study is to re-design current practices, FR5 can be removed from the matrix. This results in the simplified compressed matrix seen in Figure 5 below.

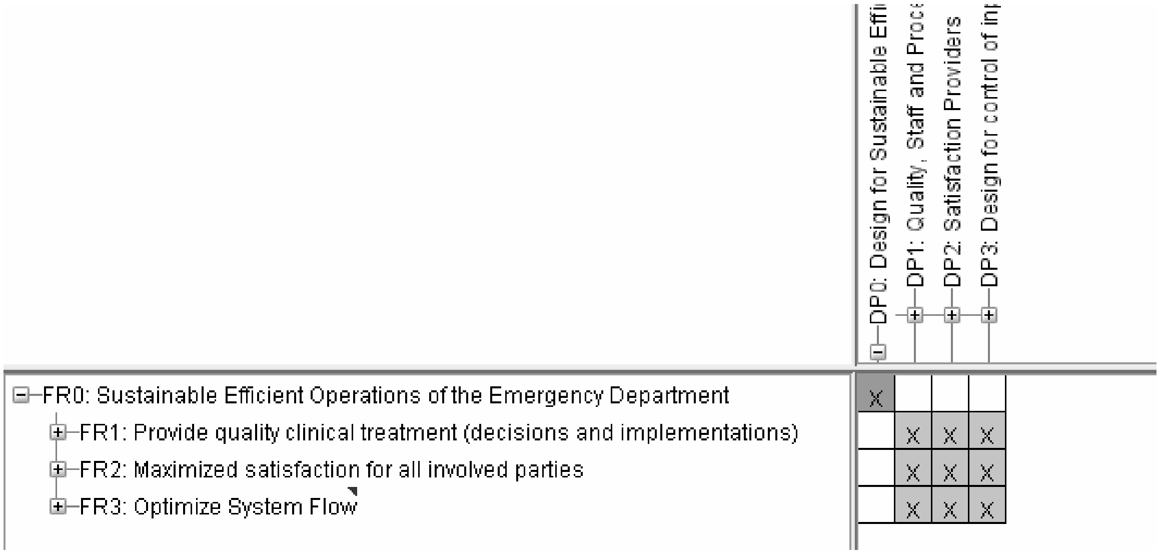


Figure 5: Simplified, Compressed ED^3 Matrix

With the matrix simplified it can once again be expanded, however now it will be less difficult to identify problems and discuss them in greater detail. The following sections will be examples of design couplings that occur in an ED as identified using the ED^3. The couplings chosen are on a high level and therefore may seem obvious; however they illustrate the potential for using the ED^3 to identify problems which can be adopted on more detailed levels. The examples also show usefulness of the ED^3 as a communication device, since it clearly identifies problems that are otherwise generally understood but not normally, systematically shown.

2.4.1 : FR1.1 vs. FR2.1 – Staff Quality vs. Staff Satisfaction

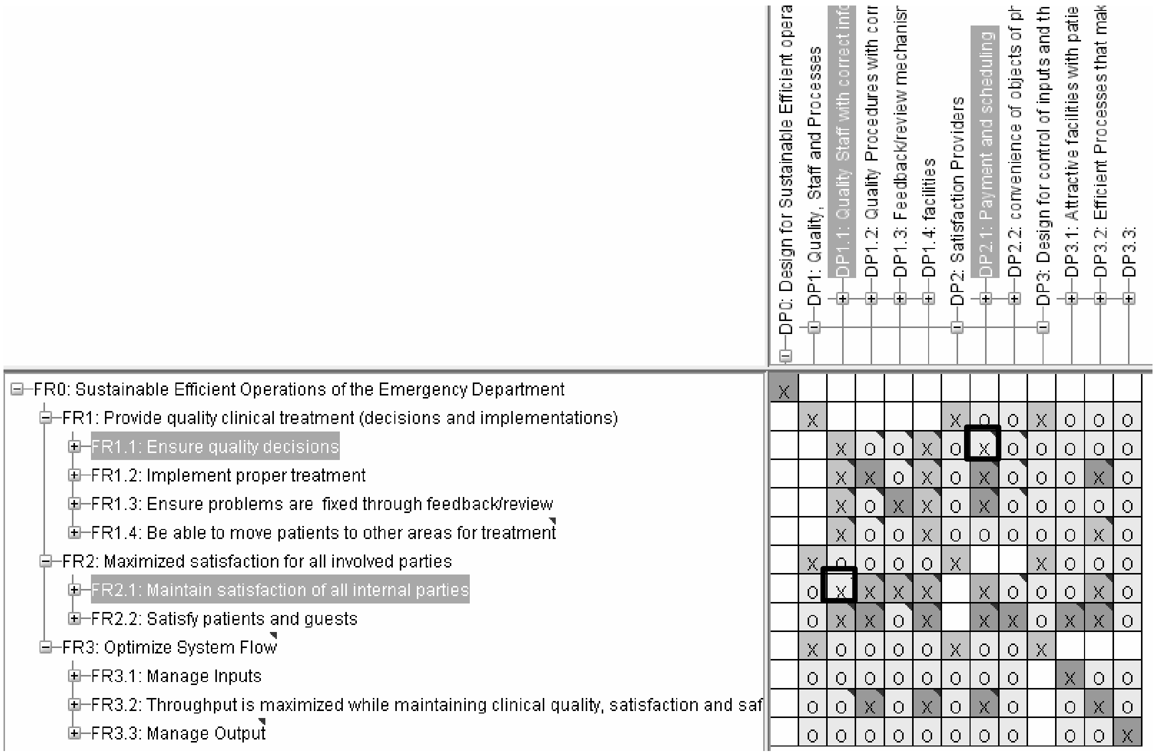


Figure 6: Simplified Matrix of ED3 Expanded one Level Showing FR1.1 vs FR2.1 Coupling

Figure 6 shows one specific coupling between quality and satisfaction. This is in fact the coupling that was mentioned hypothetically earlier, having to do with the cost of satisfying employees. The FRs and DPs that are being analyzed are highlighted and the coupling between them is denoted by a X boxes with a thick outlines.

FR1.1 calls for making quality decision, however that requires paying for quality staff, which affects the ability of ED management to afford all of their staff, in that way DP1.1 which is to hire quality staff directly affects the ability to satisfy staff as a whole due to limited funds. This means that an ED manager must make decisions that balance hiring the very best, with satisfying all current employs.

On the other hand, DP2.1 calls for payment and scheduling practices in order to maintain satisfaction. In order to maximally satisfy staff they will be scheduled such that they are never overworked, but are never bored. However in order to maintain highest quality in treatment, ideal patient/caregiver ratios must be reached that may not allow for ideal scheduling that satisfies staff. In other words scheduling to satisfy staff may affect quality.

Although this interaction is indeed a very serious problem, it is actually de-coupled given a certain amount of money. Greater funds would allow hospitals to hire enough quality staff such that necessary ratios are always reached while not overworking any specific staff member. Another de-coupling factor is the ability to hold funding constant, but improve the efficiency of the ED and lower the optimal patient to caregiver ratio.

2.4.2 : FR1.3 vs. FR2.1 – Improving Quality vs. Staff Satisfaction

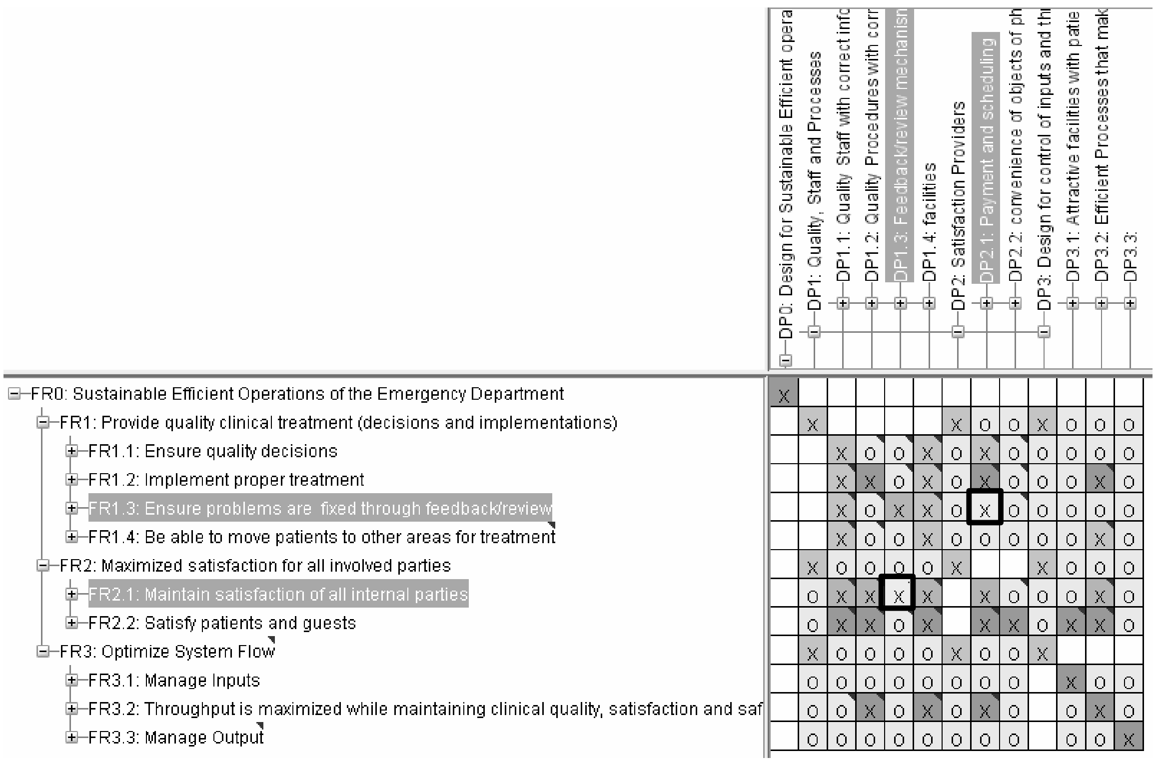


Figure 7: Simplified Matrix of ED3 Expanded one Level Showing FR1.3 vs FR2.1 Coupling

Figure 7 uses the ED^3 matrix in order to show another coupling between quality and satisfaction. In this case the coupling is between efforts to improve quality through feedback and the satisfaction of employees. It is important to receive feedback on how employees are performing; this allows management to make changes in order to improve quality operations. However performance feedback has the very strong potential of affecting staff satisfaction. Staff members want to feel secure in their jobs, if they feel that they are constantly being evaluated then, although quality may improve, they may not feel as satisfied.

Besides how feedback applies to evaluation of performance there is also staff generated feedback. Staff can offer feedback by reporting mistakes allowing for clinical staff to find the cause of the mistake and ensure it does not happen again. This has potential effects on satisfaction in that staff will not want to report a mistake if they feel it will endanger their job. In order to overcome this coupling many hospitals have offered not to punish for any single mistake as long as it is reported quickly and honestly [Leape 1998]. Staff feedback can be taken to a higher level through active feedback. In this case staff members actively seek problems and report them in order to encourage constant improvement. Such feedback is the backbone of many continuous quality improvement strategies that have been reported in the healthcare setting [Spear 2005]. By being able to provide feedback employees gain a sense of ownership, which increases satisfaction while also increasing quality.

2.4.3: FR1.2 vs. FR3.2 – Treatment Quality vs. Throughput

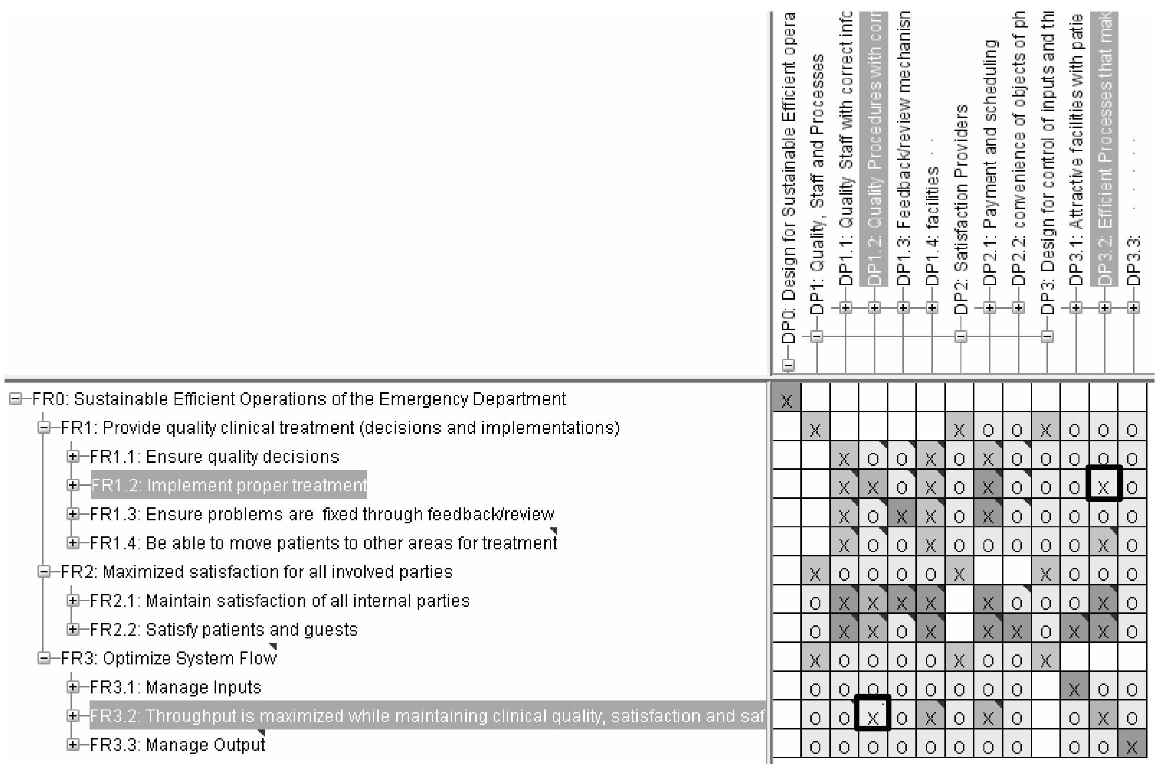


Figure 8: Simplified Matrix of ED3 Expanded one Level Showing FR1.2 vs FR3.2 Coupling

The coupling between FR1.2 and FR3.2, shown in Figure 8, is one that occurs in many kinds of systems that have to deal with product flow. It is desirable to move as many patients through the ED as fast as possible, from a productivity point of view. In the case of EDs, there is extra impetus for speed because ailments can get worse with time and thus having a patient wait for too long can be hazardous. It is also important to move patients through the system quickly in order to avoid crowding. However speedy treatment has direct consequences on quality of treatment. Pushing staff to work too fast can lead to stress and exhaustion which can be linked to harmful consequences in a treatment quality [Firth-Cozens 1997]. A balance between high throughput and high quality must be found in order to satisfy both FRs. This can be made easier through improved efficiency that would allow for higher quality and higher throughput; however the coupling would still exist to some degree.

2.4.4: FR1.4 vs. FR3.2 – Diverse Quality vs. Throughput

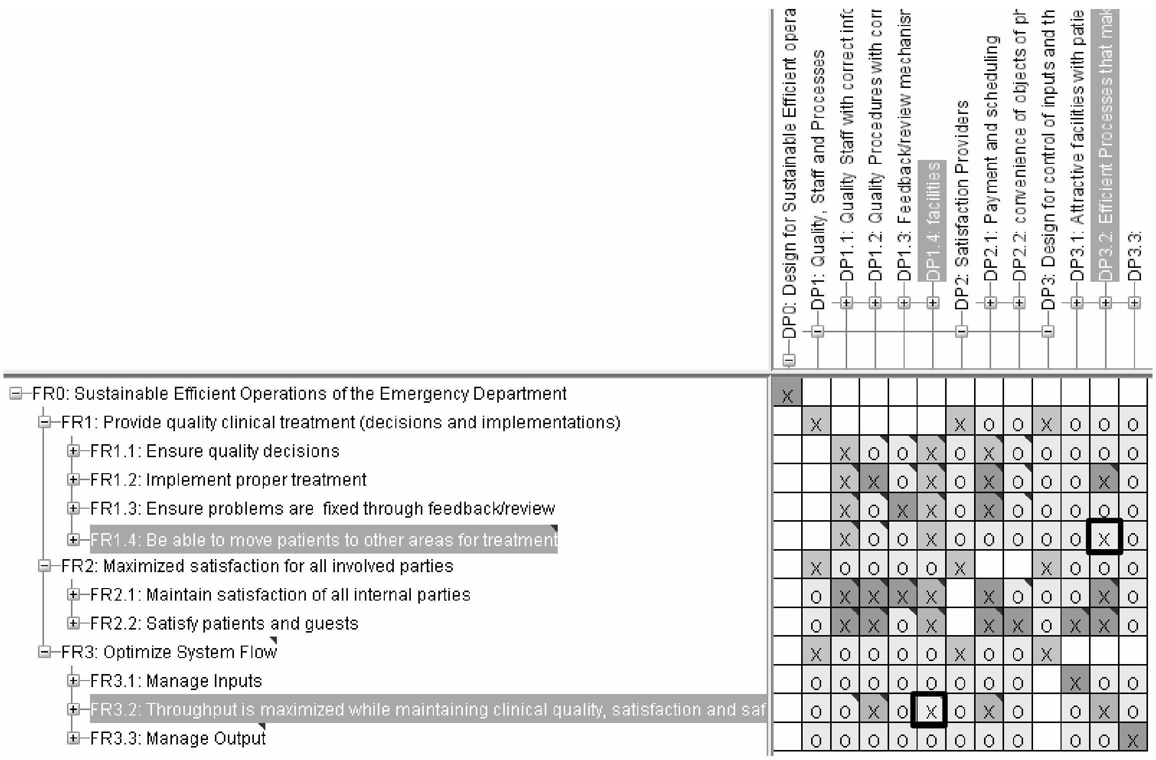


Figure 9: Simplified Matrix of ED3 Expanded one Level Showing FR1.4 vs FR3.2 Coupling

As mentioned in section 2.3, it is easy to take certain design decisions for granted when analyzing the design of a system rather than designing it from scratch. A key aspect of the design of an ED that feels strange to question is, why locate an ED in a Hospital? From a management standpoint there are many possible reasons such as infrastructure benefits of being part of a larger building (ie. Parking, Operations Overhead, Access to Hospital Food Courts etc.). In terms of the ED^3, the reason for attaching an ED to a hospital manifests itself in FR1.4. In order to provide quality treatment, the ED must also be capable of providing a diverse range of treatment; this coupling is shown in Figure 9. In some cases it is not reasonable to have an ED with all of the necessary facilities to fully treat every patient that arrives, this is why the ED must have the ability to send a patient to the larger hospital facility, after being stabilized, in order receive complete treatment.

The necessity of being part of a hospital and sending patients for admittance to the hospital has significant consequences in terms of patient throughput. Often due to bed or staff shortages or other causes, an ED patient can not be immediately sent for admittance to the hospital. This causes flow bottlenecks in the ED which then results in ED crowding [US GAO 2003].

2.5 Applying the Lessons of the ED^3

Section 2.4 pointed out only a few of the many insights into ED design that can be made from the ED^3. Although every design coupling and decision deserves attention, it was decided that it would be worthwhile to focus on one specific problem and study it. After completing the first draft of the ED^3 focus was moved to the coupling discussed in section 2.4.4 between patient throughput within the ED and the necessity of having patients admitted to the hospital.

The specific effects of a hospital on its corresponding ED became the first focus of the PCCS. Initial studies of this problem resulted in a publication that attempted to quantify the effects of hospital utilization on crowding in an ED [Kolb 2007].

An ED design that attempts to remove the admittance bottleneck between the ED and a hospital by decoupling the two parts is known as Fast Track (FT). FT successfully decouples the ED and hospital by only accepting patients that will be sent home rather than admitted to the hospital. Chapter 4 is a detailed review of the study performed on FT that took place making use of simulation tools (Chapter 3) and having the understanding provided by the ED^3.

3 Discrete Event Simulation and the Emergency Department

Chapter 2 explains how to use AD in order to systematically discover possibilities for redesigning an ED. For some of the examples provided in section 2.4, the best options for creating and analyzing possible solutions would be general management methods. For example, making an economic decision based on the trade-off between higher quality and higher pay for employees is a problem that occurs in many industries and does not require manufacturing methods to solve. However when faced with issues such as patient flow, as suggested by section 2.4.4, there are many options and decisions that can be made and therefore more technical tools may be necessary.

When making decisions in complex organizations, where it is necessary to study causes and effects within a system, simulation techniques have gained a great amount of popularity. “A simulation is the imitation of the operation of a real-world process or system over time”[Banks 1984]. Using a simulation model it is possible to study many different scenarios, where a designer can change a single specific parameter and see how this affects the outputs of the system; in other words, the designer can ask “what if?” In this way a simulation becomes useful in that it allows for predictive analysis on a system that is first being designed or on changes to a system that already exists. One specific type of simulation that has become popular for complex systems is Discrete Event Simulation (DES). When using DES the system is organized as a set of entities, these entities are acted upon by resources and trigger events. The values or states that are associated with a specific entity are assigned or changed at discrete points, as the entity travels within the system [Dooley 2002].

This chapter explains how DES has been used in the healthcare context and how a model of our partner ED was generated using DES. This DES ED model will then be used in Chapter 4 in order to test conclusions for ED improvements that were drawn from the ED[3].

3.1 Discrete Event Simulation in Health Care

Due to rising costs in healthcare it has become important for professionals to study new ways of improving treatment systems such as EDs, even small increases in efficiency can have powerful effects on decoupling parts of the system as described in Chapter 2. In the healthcare context it is not easy to try out new ideas during real time operations since any lapse in logic or in implementation can lead to endangering someone's life. This is why DES has become the tool of choice for many who are studying system changes within a clinical setting. By using DES hospital management avoids the costs of making mistakes from implementing new, untested ideas, but still may gain the benefits of finding new ideas to improve efficiency. Due to the application of DES in the healthcare setting, many new discoveries have been made and interest in using DES as well as the sophistication of DES software continues to increase [Jacobson 2006, Jun 1999].

Jun, Jacobson and Swisher performed a survey of the different studies that used DES in healthcare as of 1999. In their article Jun et al, identify two primary areas within healthcare in which DES studies are performed. The first area is patient flow. Included within patient flow are studies of patient scheduling and admissions, patient routing and flow schemes, and scheduling and availability of resources. The second area is allocation of resources. Included within allocation of resources is bed sizing and planning, room sizing and planning, and staff sizing and planning. One major conclusion of the study is the need to combine simulation with optimization techniques. It is explained that simulation merely predicts how the system will act, but that techniques are necessary to suggest ways of improving the system and then simulation can be used to test these improvements. That is exactly what is intended by mixing AD and DES in this thesis [Jun 1999].

The PCCS has used DES in the past in order to perform an ED Study [Kolb 2007]. For this study we chose to employ Rockwell Arena™. The benefits and uses of this software have been published elsewhere [Kelton 2007]. The study used a fairly simple model of the ED in order to characterize the effect of utilization levels in a hospital's Inpatient Unit (IU) on the ED. The results of this study showed a strong correlation between IU utilization and ED crowding.

However, due to the general simplicity of the model, we have created a new, more detailed model, to be used for more complex decision making and scenarios.

3.1 Gathering Data

Our study is based on the ED of Newton-Wellesley Hospital (NWH) a community, teaching hospital in Newton, Massachusetts, which is a suburb of Boston. The hospital has easy access from an interstate highway. The likely patients to come to the hospital are those who live in, work in, or are visiting the area. The hospital is also a part of a local hospital network and so it may receive some transfer or forwarded ambulance patients from its partners. Due to the nature of the high income suburban area, it is more common for NWH to deal with issues of the elderly, families, etc. rather than crimes of violence. Arrivals to the ED can occur through the walk-in entrance or through an ambulance entrance which is served by local EMS. The majority of patients are walk-ins.

Figure 10 is a depiction of the ED that was observed. This drawing was made within the simulation software and was animated to show patients as they progress through the ED. As can be seen there are three Emergency Rooms (ER). The Main ER has 24 beds 12 of which are always open (side A) and the other 12 are only open from 10am to 2am (side B). The pediatric ER has 8 beds and is open from 10am to 2am. Finally the FT has 4 beds and is open from 3pm to 11pm. The ED has 3 triage rooms two are always open and staffing is flexible based on need, the third triage room opens when all 24 Main ER beds are open. There are two X-rays, one C/T scanner, and three registration computers that are mobile.

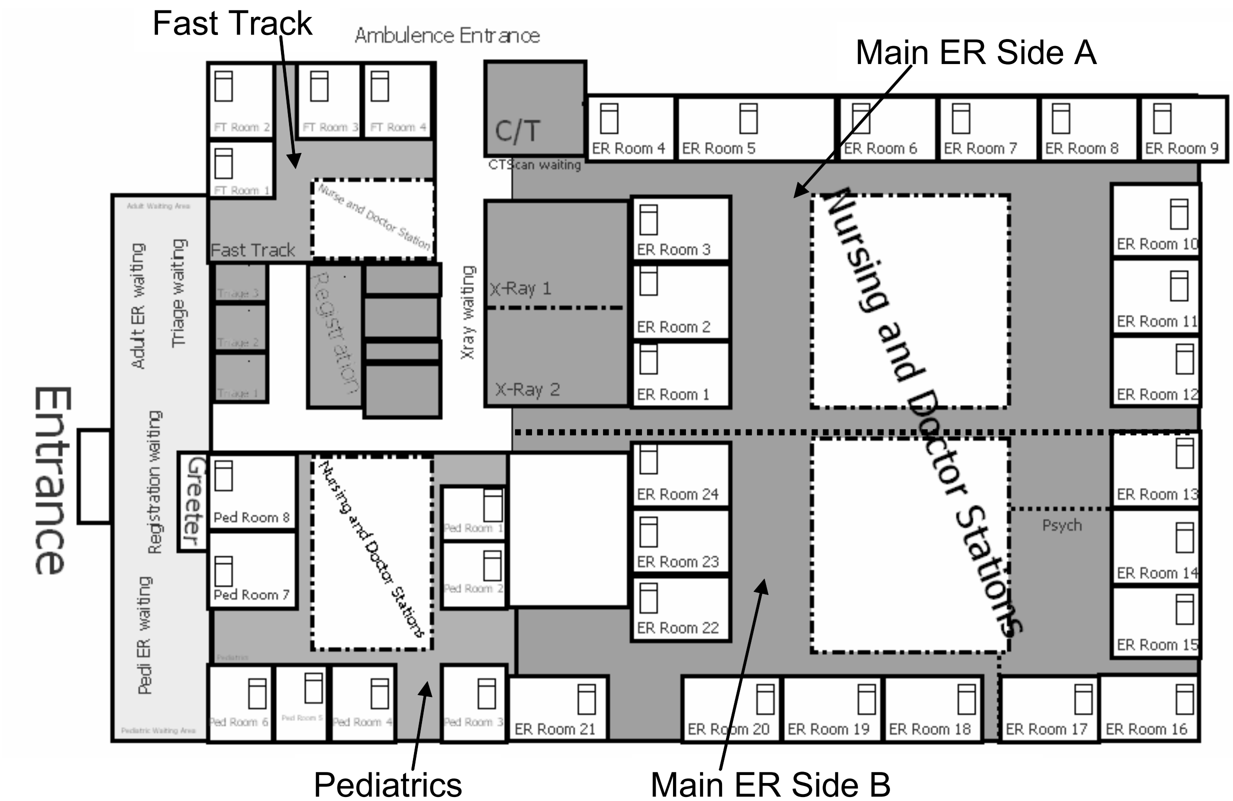


Figure 10: ED Layout

Our ED study began by preparing a detailed flow chart of the processes within the ED. Proper understanding of these processes was acquired though extensive observation of the ED at many different times of day and levels of crowding. The observations were made from many points of view: a patient, a doctor, a triage nurse, a charge nurse, a regular ER nurse and patient information. This extensive study of flow through the ED led to an in-depth understanding of the complexity involved with practical flow through an ED.

Although it may not be necessary to model the ED system with too much detail in order to perform some simple experiments, we sought to create a model of the ED that could be used for many different potential experiments. To that end it was necessary to create an extensive model of the system. The use of DES allowed us to make the sophisticated model that was necessary for our experiments, and allowed us to model the system with sufficient detail, such that the full effects of a small change to patient flow rules or process structure can be properly analyzed.

No matter how accurate a simulation is, it will not give useable results unless its inputs are properly chosen. With this in mind we worked with NWH in order to receive 12 weeks of real historical patient data, while observing all applicable Health Insurance Portability and Accountability Act (HIPAA) protocols. The data included 11540 entries, 3015 entries were discarded due to missing information or clearly inaccurate information, leaving 8525 useable patient records. The patient data included important times for tracking a patients flow through the ED, such as Triage to Bed (TTB), Triage to Doctor, Greeting Time and Length of Stay. These tracking times are summarized as a time line in Appendix B1. The information also included dates and times of the patient's visit as well as the patient's age, ESI at triage and at disposition, and to where they were discharged.

From the data that was provided we documented an arrival pattern of all ESI levels for one week taken from an average of all of the arrival patterns for all 12 weeks. This was the input to our model. Using the patient data we were also able to calculate percentages for assigning the attributes of a patient as they are created in the simulation model.

3.2 Conceptual and Simulation Model

When a patient enters the ED they approach the greeters desk. At this desk they provide basic information as well as primary complaint. This information is passed to a triage nurse who works on a first come first served basis unless the symptoms of the patient require immediate attention. The triage nurse does a preliminary examination of the patient, assigns the patient an ESI level and chooses what Emergency Room is appropriate for the patient (Pediatric, Main or FT). If the patient is under 18 they will be sent to pediatrics, if not and the patient has a low acuity they may be sent to FT (if it is open), otherwise they will be sent to the main ER. Before being sent to their beds the patient will be registered. In any room in the ED, patients may undergo a nurse examination, nurse treatment, doctor examination, doctor treatment, testing, and consultation. Some patients may experience any one of these processes more than once depending on their needs. Finally they are discharged either home, to the hospital, to a different hospital, or to any other location. The patient's bed is then cleaned and a new patient enters. The flow chart of the process, created in Microsoft Visio can be found in Appendix B2.

Our simulation model was built by closely following the actual processes through which a patient goes. Figure 11 shows the structure for the high-level model of the ED where each block represents a detailed sub-model.

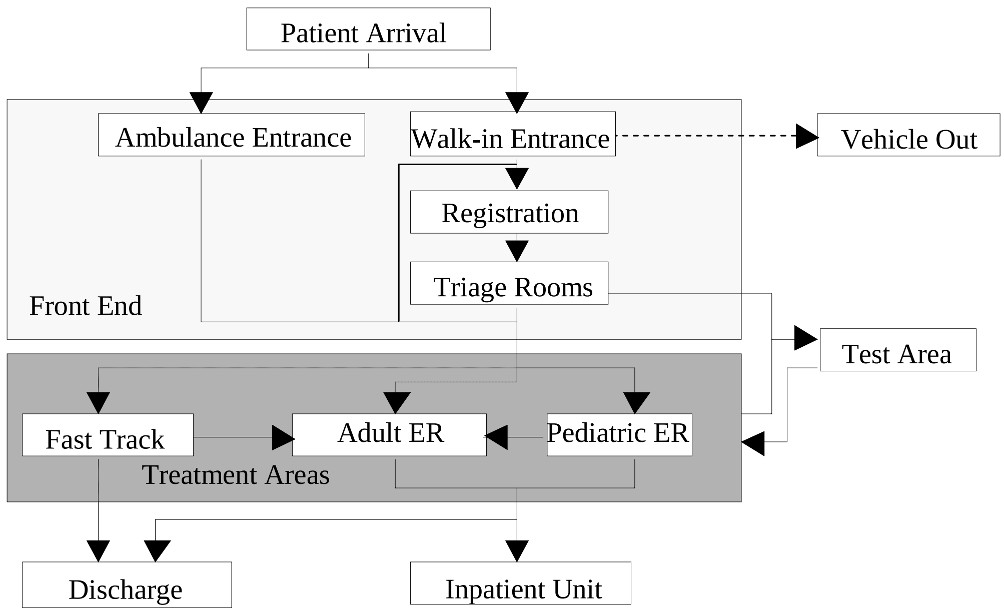


Figure 11: Conceptual simulation model

As seen in Figure 11 patients begin in the patient arrival sub-model. In this sub-model patient entities are generated, and then assigned the attributes that will guide how the patient progresses through the ED. Within the patient arrival sub model, we made the percent of patients that will be assigned to FT for ESI 5, ESI 4 and ESI 3 acuity levels into variables that can be controlled externally. We also made the hours that patients can be assigned to FT controllable.

External control is preformed using a program that comes with the DES software known as the Process Analyzer. This program allows a user to display a list of control variables that have been established in the simulation programming, and also a list of response variables that result from a run of the simulation. The program makes it simple for a user to change variables and quickly view the results of the changes.

After leaving the patient arrival sub-model, ambulance patients and walk in patients are then sent to different entrances. In these entrances there are recording and assignment blocks for statistical and routing purposes. Walk-in patients that have ESI 1 are sent directly to a bed while all others are sent to registration, which is a simple delay.

After registration, walk-in patients of ESI 2-5 go to triage, and gain access to a triage nurse. After being seen by a triage nurse patients can be assigned to receive preliminary testing. Patients are then sent to wait for entry into the appropriate treatment area. It is assumed that ambulance patients gain some level of triage on the ambulance and therefore are sent directly to their treatment area rather than going through triage.

When assigned to the main ER a patient entity must wait to be assigned to an open bed. The patient is then assigned a nurse. Each nurse has the capacity for three patients. The nurse performs an examination which is programmed as a delay for the patient. After being seen by a nurse the patient waits for a doctor for further examination which is also a delay. At this point all patients undergo testing, no patient is sent for testing more than twice. Throughout the testing process patients release and wait to be seen by doctors as needed. The patient may then be seen by a consultant, who will relieve the doctor and can send the patient for more testing. The patient then receives treatment by a doctor; the length of time for this treatment can be externally controlled. Then the doctor is released and there is a final nurse treatment, the duration of which can also be controlled. After treatment, IU bound patients wait to be assigned a free IU bed and are then transferred, while patients to be released from the ED are discharged. Finally the nurse and bed are both released.

The pediatric ER is the same as the main ER except that it has a module which will send patients to the main ER if they are waiting for a pediatric bed when the room closed. Even though the doors to the Pedi ER close, resources continue to work until the beds are empty. Both ERs have programming that will make a patient leave without being seen if they have an ESI 3 to ESI 5 and have been waiting for a bed for more than 4 hours.

Like the pediatric ER, the FT begins with a module that will send patients to the main ER if the FT is closed, but resources continue to work until beds are empty. Like in the other treatment areas, an FT patient begins by waiting for a bed, and then a nurse performs a preliminary examination. FT patients are tested once at most and are then seen by a physician. Then patients receive treatment from their physician. The duration of this treatment is externally controllable, and the inputs for this duration are the treatment times, explained in more detail section 4.3. Finally the patient is discharged.

A patient who is being admitted to the IU will wait in their ED bed until an IU bed is available. Once a bed becomes available, they leave the ED. The IU sub model is a simple delay process where the patient is held for some period of time, after which they are discharged out of the hospital. It should be noted that the discharge volume exhibits a distinct pattern in most hospitals – heavily concentrated on the mid- to late-afternoon hours. To model this, we used a Poisson distribution function that was adopted from similar studies [Kolb 2007, Williams 2006].

3.3 Validation and Verification of Model

Having created the simulation model and generated proper inputs extensive verification and validation measures were taken. We began validation by using already established processes [Banks 2005, Sargent 1999]. We performed an iterative process where the simulation model is repeatedly being compared to our conceptual model, which is being compared to the actual system. To assist in verification, hospital administration was consulted and analyzed both the conceptual model and the simulation itself. Finally tests were performed to ensure that the simulation acts as predicted.

Despite our thorough verification and validation, it is important to note the limitations of discrete event simulation and our model. When using simulation it is difficult and often unnecessary to get results to exactly match the empirical numbers and data. This is due to the nature of a simulation model, however we were cautious to ensure that all data is within a statistically significant range of the real patient data.

4 Case Study: Fast Track

In section 2.4.4, the ED^3 suggests that the coupling between an ED and IU causes problems in throughput. As noted earlier, Fast Track (FT) is an ED design that attempts to remove the admittance bottleneck between the ED and a hospital by decoupling the two parts. FT successfully decouples the ED and hospital by only accepting patients that will be sent home rather than admitted to the hospital. In this chapter, we analyze the design and implementation of FT through experiments with the DES model described in Chapter 3. We performed three experiments on the FT, adjusting: operation hours, patient inputs and size. The purpose of this study is to show that the ED^3 accurately identified an opportunity to improve patient flow, as well as gain practical insights on how to design a more efficient FT and ED system as a whole.

The experimental results show that the benefits of FT are derived by avoiding bottlenecks caused by transfer from the ED to the hospital inpatient wards. However, FT does increase waiting times for high acuity patients, by taking up resources to which these patients would otherwise have priority. To justify the use of FT, it must also accept patients with longer treatment times, as long as they will not require transfer to the hospital's inpatient wards. FT must be sized appropriately to minimize the reduction of resources available to high acuity patients.

4.1 Low Acuity Patients and Fast Track

When choosing who to treat first, hospitals will prioritize based on patient acuity and as mentioned in section 1.4.1 many hospitals define acuity using ESI [Gilboy 2005]. Only after a low acuity patient has been waiting for a long time will the ED staff raise their priority [Garcia 1995]. This means that when waiting times have become very long, it is the low acuity patients that must wait the longest. Although studies have shown that the existence of low acuity patients in the system does not increase waiting times for higher acuity patients, hospitals are a business and they want make all patients happy, therefore is it necessary to accept long waiting times for low acuity patients or can we help these patients while not harming others [Schull 2007]?

While waiting to be seen, what was originally a minor injury can become more complicated. Long wait times can also make a patient become irritable and cause trouble for staff and other patients. Sometimes the patients will wait until they are seen, but in other instances as mentioned in section 1.2.1, the patient will choose to leave without being seen (LWBS) by ED staff. Figure 12 shows the number of patients who left without being seen during a two month period at NWH. It is clear from this figure that the majority of patients that left are those with lower priority, having an ESI of 3-5. While we can not make a generalization out of one sample, it is still reasonable to assume that many of LWBS patients are relatively low acuity.

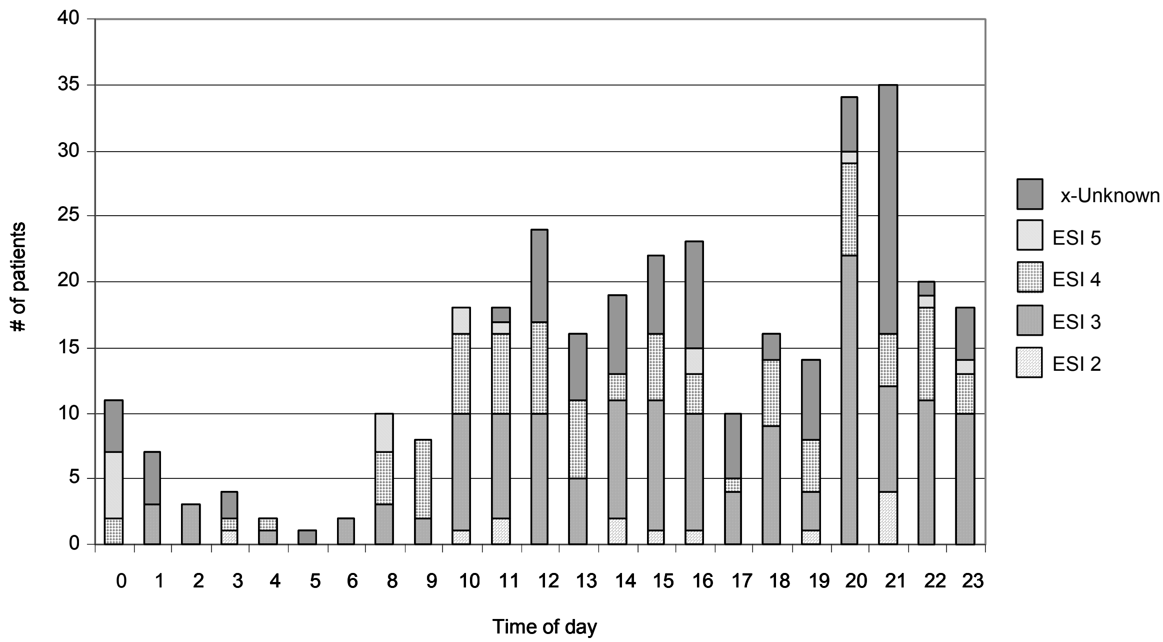


Figure 12: Left Without Being Seen (LWBS) patient statistics (from 2/4/2007 - 5/16/2007, 102 days)

Significant waiting times that cause low acuity patients to walk away from necessary medical care are partially the result of a justifiable priority-based queuing practice. When demand exceeds resources, the system needs to figure out who requires the most immediate care and who can wait. The problem with this intuitive and seemingly fair principle is that this can enter the system into a dangerous cycle. When the delay is caused by its exit being blocked, few patients leave the system while more high-acuity patients enter. These high-acuity patients tend to require longer times for treatment, and more importantly tend to join the group who are boarding in the ED. This further reduces the effective capacity of the system, leading to a worse demand-supply imbalance. Once the system enters this cycle it becomes even more difficult for low acuity/priority patients to obtain a bed.

To break the cycle, it is necessary to maintain the effective capacity of the system above a certain level. One way to achieve this is to allocate a portion of the system capacity to never get blocked by exit congestion. This is the idea behind FT. FT is a subsystem within the ED where some beds are set aside to only treat low acuity patients. A past simulation study of FT showed a reduction of length of stay for low acuity patients by 25% without negatively affecting the high acuity patients [Garcia 1995]. Other studies have similarly shown FT to be useful for reducing waiting times in the ED, and have tied the use of FT to a decrease in LWBS patients [Fernandes 1997, Cooke 2002, Nash 2007].

Although the concept of FT is well known, there seems to be a need for clearer understanding of what makes it work and how to use the FT resource to its greatest potential. Many hospitals implement FT as simple examination rooms staffed by a nurse or nurse practitioners. Others will have doctors on call, and still others will have doctors assigned specifically to FT [Fernandes 1996, Hampers 1999, Meislin 1988, Wright 1992]. This diversity in implementation shows what the optimal way to supply and operate FT is yet unclear.

Even the designation “Fast Track” implies a certain amount about how practitioners perceive it should be run, leading to the acceptance of only patients that will require a short treatment time. In one description of FT it is said that the FT is for treating low acuity patients in a “speedier manner” and mentions a “60-minute ideal throughput time that should be the goal for a Fast Track” [Williams 2006]. However, it is possible that having strict time requirements on FT may not lead to treating more patients, but may actually result in patients being sent to the main Emergency Room (ER) rather than FT because the patient had a long treatment time, despite their low acuity. Having a FT that only treats those with very low acuity would make the FT more likely to underperform by leaving resources unused, due to a lack of patients that meet the strict criteria.

Despite underperformance in terms of resource utilization, FTs have been successful in reducing the waiting time for low acuity patients. NWH used to have a FT that was only capable of treating low acuity patients. When the hospital built a new ED, four fully functional rooms were set aside for FT. This investment of resources has the potential to change the dynamics of how the ED uses FT since now FT can treat higher acuity patients if needed. This change in potential warrants investigation. The study will clarify the mechanisms that make a FT successful and generate a better understanding of why a FT has its positive effects on patient flow. The results of this study will be readily applicable to already existent FT systems and will offer hospital administrators design suggestions for future implementations of FT.

4.2 Problem Definition

As mentioned earlier, NWH has an ED with 24 main ER beds – 12 are open for 24 hours and 12 for 16 hours, 8 pediatric ER beds that are open from 10am to 2am, and 4 FT beds that are open from 3pm to 11pm. The FT is staffed by one physician and one nurse and all FT beds are fully equipped like any other ER bed. Pediatric patients are not eligible for FT, and there is no sharing of Nurses, Doctors or physical resources between the ER, FT and Pediatrics. Therefore the FT system is completely independent from the pediatric ER.

Our observations showed that after a patient is triaged, they are assigned to the FT if they meet the following criteria:

1. Main younger than 65
2. ESI 4 or 5
3. Estimated test and treatment time is less than 60min

It has already been discussed that the four FT beds can not be delayed due to patients waiting for transfer to the hospital and the patients in FT have a low amount of time in the ER. Because of this, beds open up quicker and the wait time for a patient assigned to FT is significantly lower than if they had been assigned to the main ER. This decrease in waiting time for low acuity/priority patients is indeed the purpose of running a FT. However as the amount of resources being put into FT increases, we must ask the fundamental question of: *If, and why, dedicating resources to low-acuity patients is better than using them towards regular ED capacity.*

NWH’s FT beds are fully capable of being used as normal ER beds. Since these fully capable resources are dedicated only to low-acuity patients, low-acuity patients benefit, but high-acuity patients are negatively effected by the reduction of resources accessible to them. This loss of accessible resources may be offset depending on how many low-acuity patients are sent to FT; as the FT gets more crowded the benefit of FT to low acuity patients becomes less apparent, however the penalty that had been inflicted on the main ER patients becomes smaller, and vice versa. In this study we simulate the ED and propose different usages of FT to find an optimal usage point that balances the pros and cons of operating a FT. The two key performance indicators from which we draw our conclusions are patient throughput and time-to-bed.

4.3 Modeling Fast Track

Using the patient data described in Chapter 3 we were able to calculate percentages for assigning all of the attributes of a simulated patient as they enter the system through the patient arrival sub-model. This includes the percentage of each ESI patient that is pediatric, arrives by ambulance, will be transferred to the IU, etc. The only percentage that could not be calculated was the patients who were sent to FT. The ED that we studied did not include this information in their electronic medical record system. However, knowing what patients were sent to FT by the actual ED is only useful for validating the model, it is not necessary experiment itself. The design of this study was to propose and analyze our own rules for assigning patients to FT, in order to explore the dynamics of FT. Therefore not knowing what patients were actually sent to FT was good, since it did not bias us in our assignment decisions. The following criteria were used to pick eligible patients and all were available in the historical data:

1. Younger than 65
2. ESI of 4 or 5
3. Entered the ED during FT hours
4. Would not require treatment in the IU

Patients who meet these criteria comprise the population a subset of which will be sent to the FT: hence we call this group “potential FT patients”. Even using these criteria it was unclear whether the system dynamics made it beneficial to send all eligible patients to FT. With this in mind we wanted to be able to study the effect of sending a selected amount of eligible patients to FT in order to discover the optimal level of usage. To make this possible we separated the data for the eligible patients and organized them by ESI. Once separated by ESI, the patients were sorted by time in ER, which was the difference between time to disposition and TTB. The use of time in ER eliminates time variability due to different discharge times and time spent waiting for a bed due to crowding of the real life ED.

Once this was done we made separate data sheets including a different percentage of patients, always beginning with the lowest time in the ER. A study of the data allowed us to document how much time in the ER corresponds to what percentage of patients. Figure 13a is a histogram showing this data for ESI 4 and Figure 13b is for ESI 5.

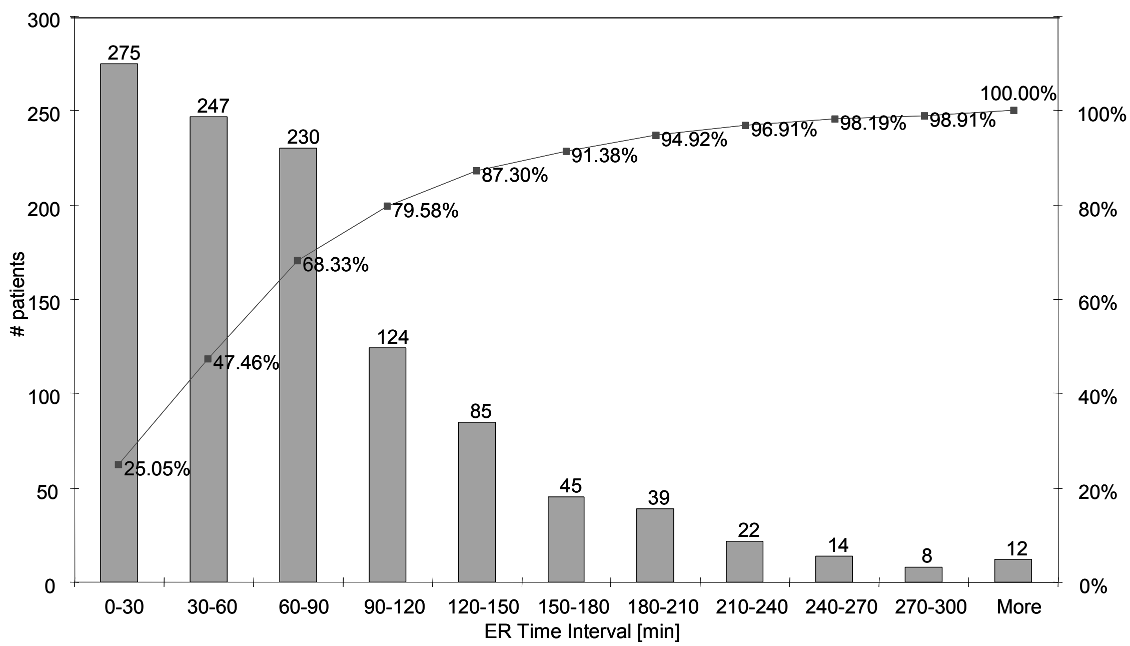


Figure 13: a) Histogram of ESI 4 FT candidate patient's time in ER

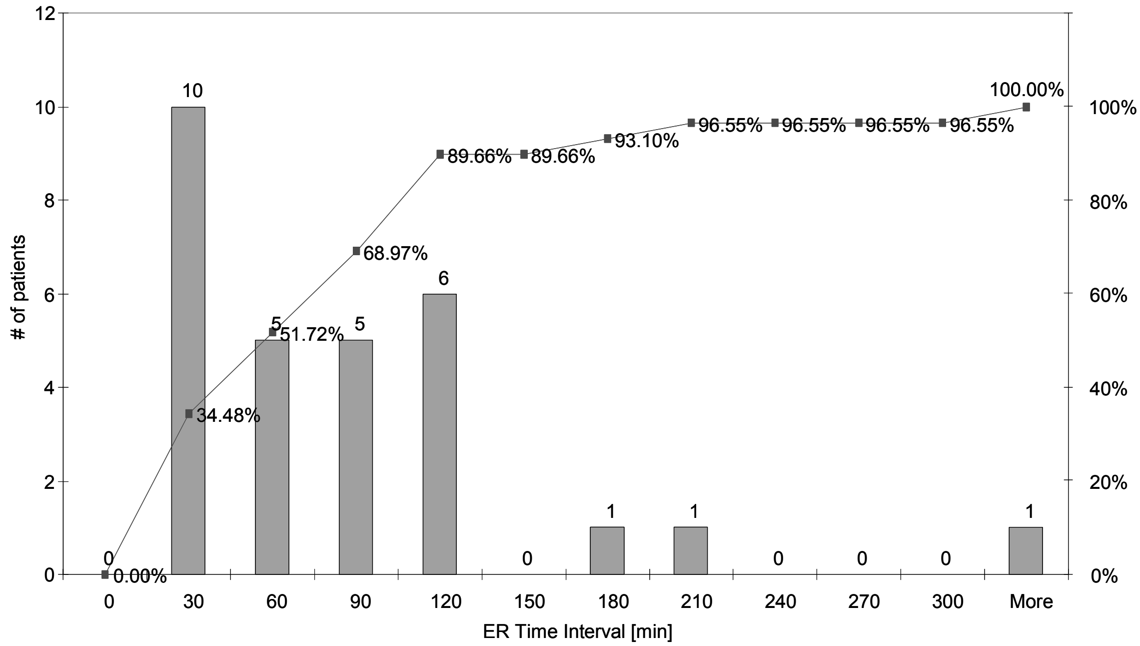


Figure 13: b) Histogram of ESI 5 FT candidate patient's time in ER

Using the data generated we were able to identify which patients were included in each percentage and separated the patients for 30%, 50%, 70%, 90%, and 100%. With the separation complete, it was possible to input the treatment data into the Input Analyzer, which is part of the Arena discrete event simulation software and fits data to a distribution curve that is useable by Arena.

The model of FT, calls for an input of treatment time for a patients delay when seen by the doctor. Unfortunately this time is not monitored by the ED. The closest recorded time to estimate this treatment time was time in ER. However time in ER includes waiting for a doctor to be available, testing, waiting for disposition, nurse treatment, etc. All of these factors are already included in our model, and so using time in ER for treatment time would mean double counting these times. To make up for this we divided the time in ER by three to estimate treatment time. This decision was based on conversation with ED staff. It was this treatment time that we entered into the Input Analyzer.

We fit the data for each percentage to the same type of distribution, and entered the coefficients as variables in Arena, allowing us to externally change which treatment curve, depending on percent of admittance, we chose to use in our experiment.

Since there were so few ESI 5 patients, and their treatment time was relatively low it was impractical to have a different curve for every percentage. Using the input analyzer we fit the ESI 5 treatment times to a triangular distribution, which requires the input of a minimum value, a most likely value and a maximum value respectively. The Arena formatted equation we used was:

ESI 5 Treatment time = TRIA(1,3.48,50)

For ESI 4 we had enough patient data to have different fits for each percent of patients admitted to FT. The fit used for all the percents was a gamma distribution of the form:

ESI 4 Treatment time = -.001 + GAMM(G1,G2)

Table 1 has the different green percents and the values for G1 and G2 for each.

Table 1 Distribution coefficients for each ESI 4 percentage.

Percentage of ESI 4 sent to FT	G1	G2
30	1.30	3.76
50	2.62	2.89
70	5.43	2.11
90	9.63	1.71
100	16.80	1.30

4.4 Experiments for making the most out of FT

As mentioned above, the concept of FT has already been developed and has proven useful in many hospitals. However our observations found that utilization levels may not be as high as they could be, meaning that the FT resources may be wasted. To test how better to implement FT, and create a new paradigm for administrators to follow, three experiments were run with the intent of increasing FT utilization:

1. We study FT patient arrival patterns and adjust operation hours to match patient arrival.
2. We adjust how many and which patients are permitted to enter FT
3. We adjust the size of FT to determine its maximum resource allotment.

All simulation runs have a 74 day run time including an 18 day warm up period, and is replicated 20 times. The program then takes statistics which are used in our results.

4.4.1 Changing FT Open Hours

Currently the FT is open for 8 hours, 15-23. Figure 14 shows the amount of potential FT patients that would arrive during different 8 hour periods. From the figure it can be seen that the current operating hours may not actually be ideal for accepting the most FT patients, since more potential FT patients arrive during other 8 hour periods such as 9-17.

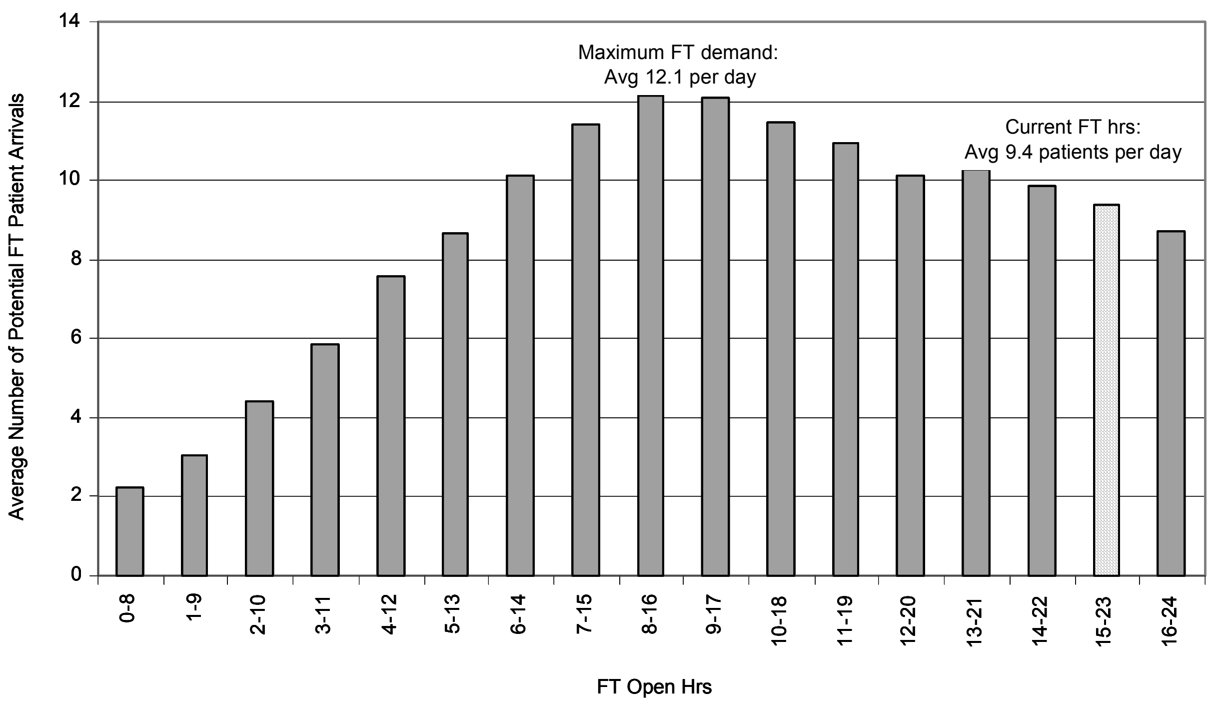


Figure 14: Potential FT patient throughput by 8 hour schedule

For this experiment, we set the percent of ESI 4 and 5 patients being sent to FT to be 90% and in the process analyzer controlled the opening and closing times for FT starting with 15-23, then 16-24, 14-22, 13-21 down to 0-8.

4.4.2 Changing Patient Inputs

We observed and have already explained that not all ESI 4 and 5 patients are admitted to FT even during FT operation hours due to the time their treatment would require. However we have theorized that it is the fact that FT does not get delayed due to transfers to the IU that makes it successful, not its speed of treatment. It is feasible to increase utilization by increasing the amount of patients that are admitted to FT even if they have longer treatment times. For this experiment we used the process analyzer to study the effects of changing the percentage of ESI 4 and 5 patients sent to the FT for the scenarios of 30%, 50%, 70%, 90%, and 100%, with patient treatment times increased accordingly as prescribed in table 1.

Continuing with the same understanding of the purpose of FT we studied the effect of sending ESI 3 patients to FT. We calculated the treatment times for ESI 3 patients using the input analyzer in the same manner as the ESI 4 and 5 patients. However our calculations were admission rates of 5%, 15%, 20%, 25% and 30%. The general curve chosen to fit the ESI 3 pattern was a Beta curve as follows:

ESI 3 Treatment Time = B1*Beta(B2,B3)

The values of the variables for each percentage are in Table 2.

Table 2. Distribution coefficients for each ESI 3 percentage

Percentage of ESI 3 sent to FT	B1	B2	B3
5	15	2.15	1.60
10	24	1.41	0.93
15	31	1.45	0.97
20	39	1.77	1.34
25	46	1.54	1.15
30	54	1.51	1.19

The experiment was then run keeping ESI 4 and 5 at 100% FT admittance and increasing the percent of ESI 3 patients admitted to FT. Throughout the experiment we used the reference scenario where there was no FT and all FT resources are used in the main ER for comparison.

4.4.3 Changing Size of FT

Even when accepting more patients, it may be the case that there simply are not enough patients to properly utilize all of the resources in FT. These unused resources may then be more useful for reducing patient waiting time if used differently. This experiment was designed to see the results of changing the amount of rooms that are devoted to FT. To accomplish this there were 10 different scenarios run. Table 3 describes the different scenario parameters.

Table 3. Parameters for FT size scenarios

FTBeds/ERBeds	# FT Docs	#Extra ER Doc	ESI5 %	ESI4 %	ESI 3 %
0/28	0	1	0	0	0
1/27	1	1	90	90	0
2/26	1	1	90	90	0
3/25	1	1	90	90	0
4/24	1	0	90	90	0
0/28	0	1	0	0	0
1/27	1	1	100	100	15
2/26	1	1	100	100	15
3/25	1	1	100	100	15
4/24	1	0	100	100	15

4.5 Results and discussion

4.5.1 Changing FT Hours

The purpose of this experiment was to change the 8 hour block that the FT was open to match the time period when the max amount of potential FT patients were entering the ED. This was meant to increase FT utilization which should also help ER throughput. Figure 15 shows how the FT throughput changed with shifting open hours.

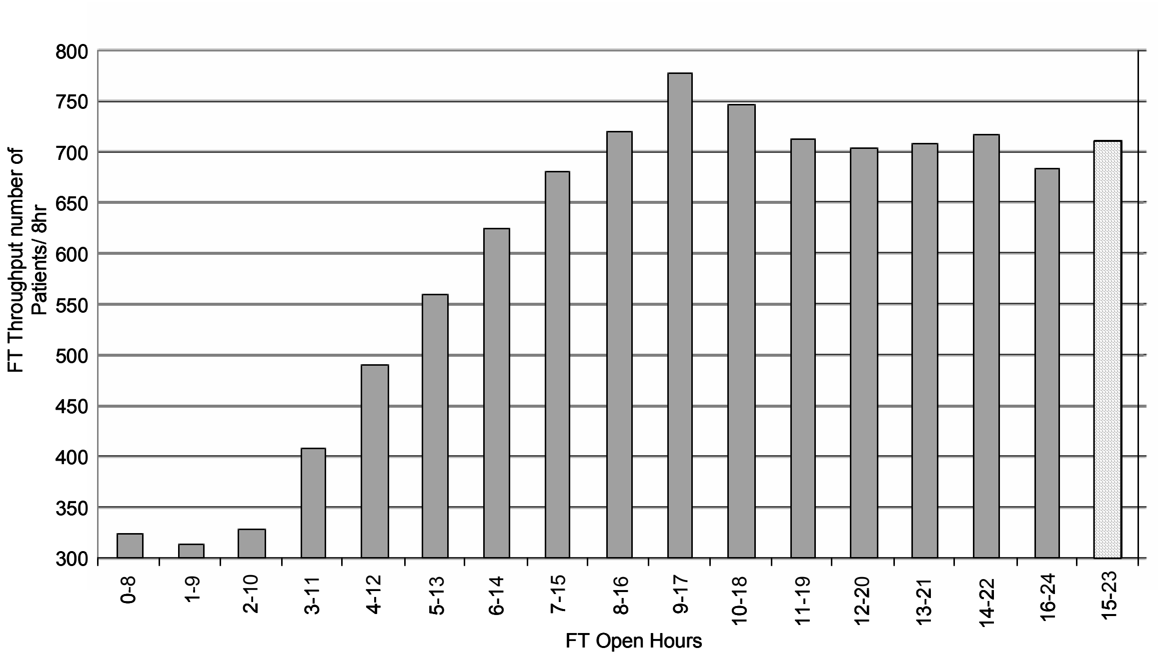


Figure 15: Total FT throughput with shifting open hours

Comparing Figure 14 to Figure 15 shows that the assumption upon which this experiment is based is correct. Figure 14 implies that setting the FT hours from 9-17 would create the largest throughput through FT and that is exactly what can be observed in Figure 15. However, Figure 16 shows total relevant throughput for the main ER which includes all patients in the main ER who are not bound for the IU and all FT patients. The reason IU bound patients are not included in relevant throughput is that they have high priority in the ED and are unaffected by changes in FT and therefore including them would merely clutter the data.

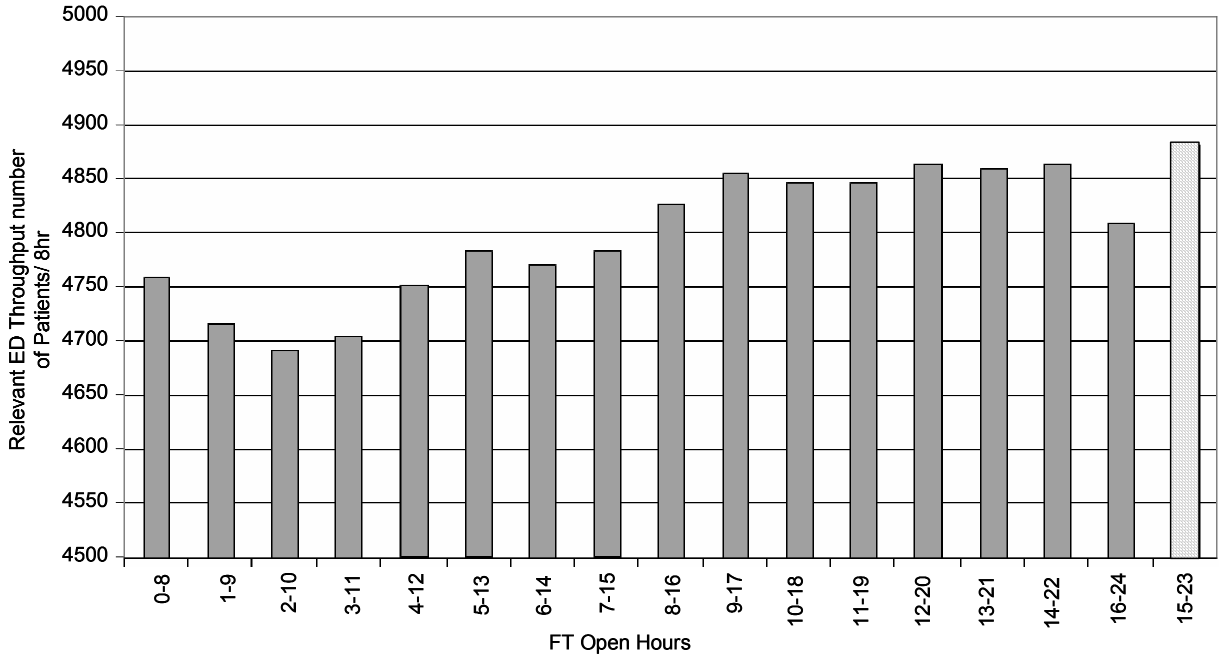


Figure 16: Total relevant throughput

As can be seen from the figure even with the increase in FT usage, the relevant throughput actually decreases when shifting the open hours. This is because although the FT has the primary purpose of decreasing the wait time for low acuity patients, it also serves the purpose of removing those patients from competition with higher acuity patients. Figure 17 shows total patient volume during the 8 hour windows.

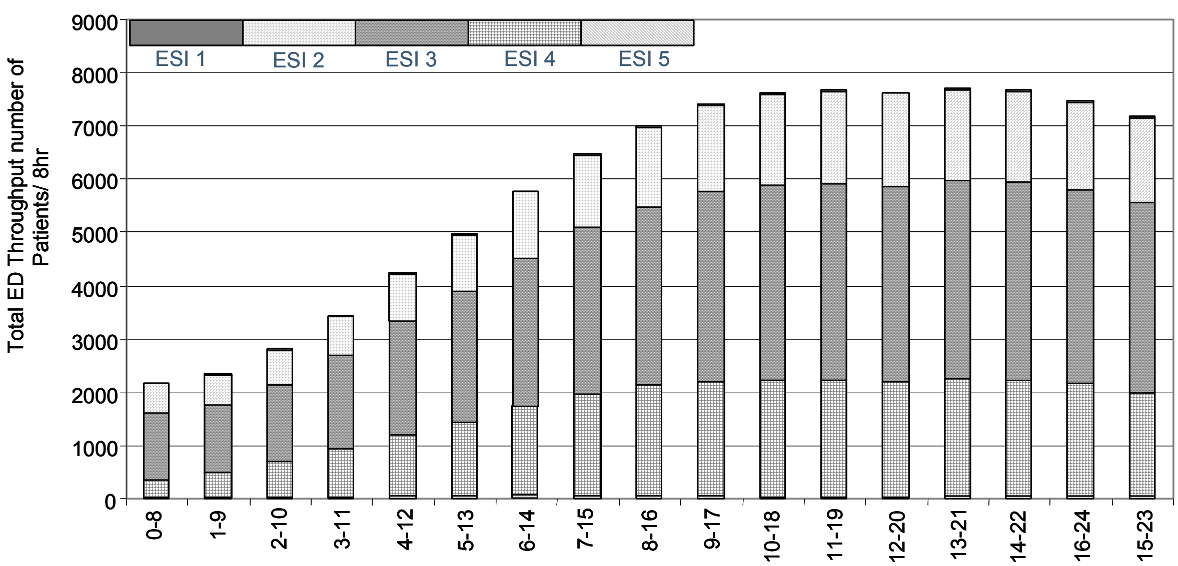


Figure 17: Total patient throughput by 8 hour window

As can be seen in the above figure, although the 9-17 block may be the time when the most ESI 4 and 5 patients are entering the system, it is not the time when the most high acuity patients are entering the system. On the other hand by 15:00 many high acuity patients have been entering the system for hours and opening the FT alleviates the ED when it is most useful to the main ER. Therefore, from the point of view of total ER throughput, the optimal time to schedule the FT is in fact dependent on the crowding state of the whole ED, not just the time when the most low acuity patients are arriving.

4.5.2 Changing Patient Inputs

The purpose of this experiment was to quantify the effect of FT on the amount of time it takes for all ED patients to be assigned a bed once they have gone through triage, Triage to Bed (TTB) times. This experiment also served to verify the assertion that FT benefits low acuity patients by bypassing exit delays, not by providing fast treatment. Figure 18 shows how increasing FT usage also increases ER throughput. It can be seen that low usage of FT is worse than the 28 bed scenario, where all FT beds act like main ER beds, while higher usage is better. The insert to the figure shows how each of the FT usage scenarios compare to the 28 ER bed scenario. The data in Figure 18 provides a good argument for the active use of FT, but does not prove that this new usage of FT still fulfills the original purpose of decreasing low acuity waiting time.

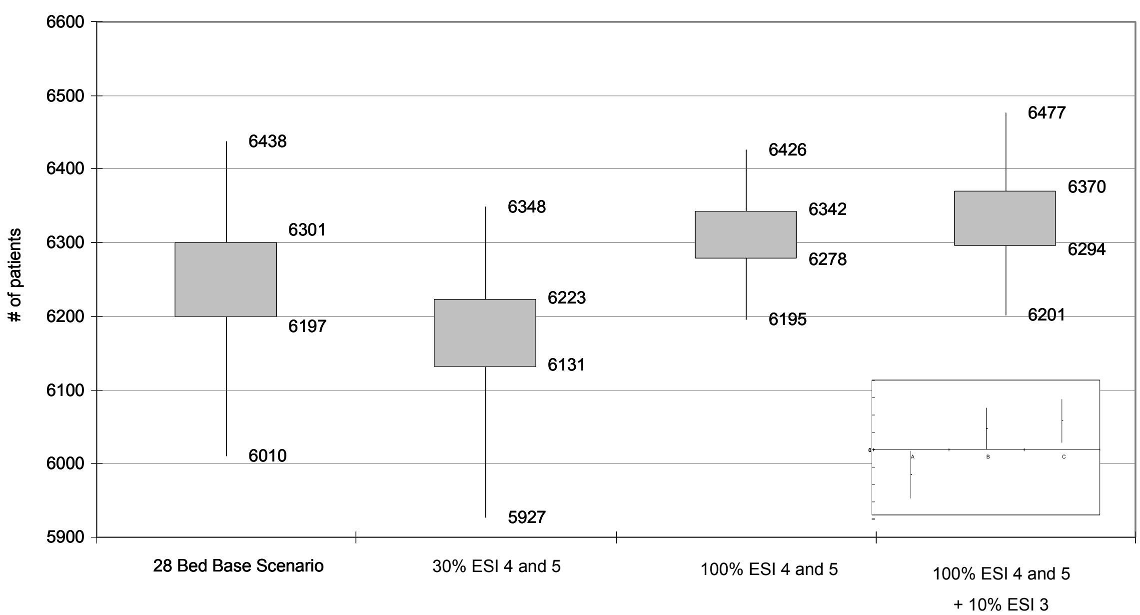


Figure 18: Total ER throughput with increasing FT usage

Figure 19 shows the TTB for ESI 4 patients who are potential FT patients, TTB for ESI 4 patients who do enter FT, a weighted average of the two, and a line for the 28 bed case for comparison. The figure shows that as FT use increases the TTB for FT patients also increases, however the TTB for potential FT patients decreases and the weighted average decreases until 90% is reached and then follows the FT patient trend of increasing.

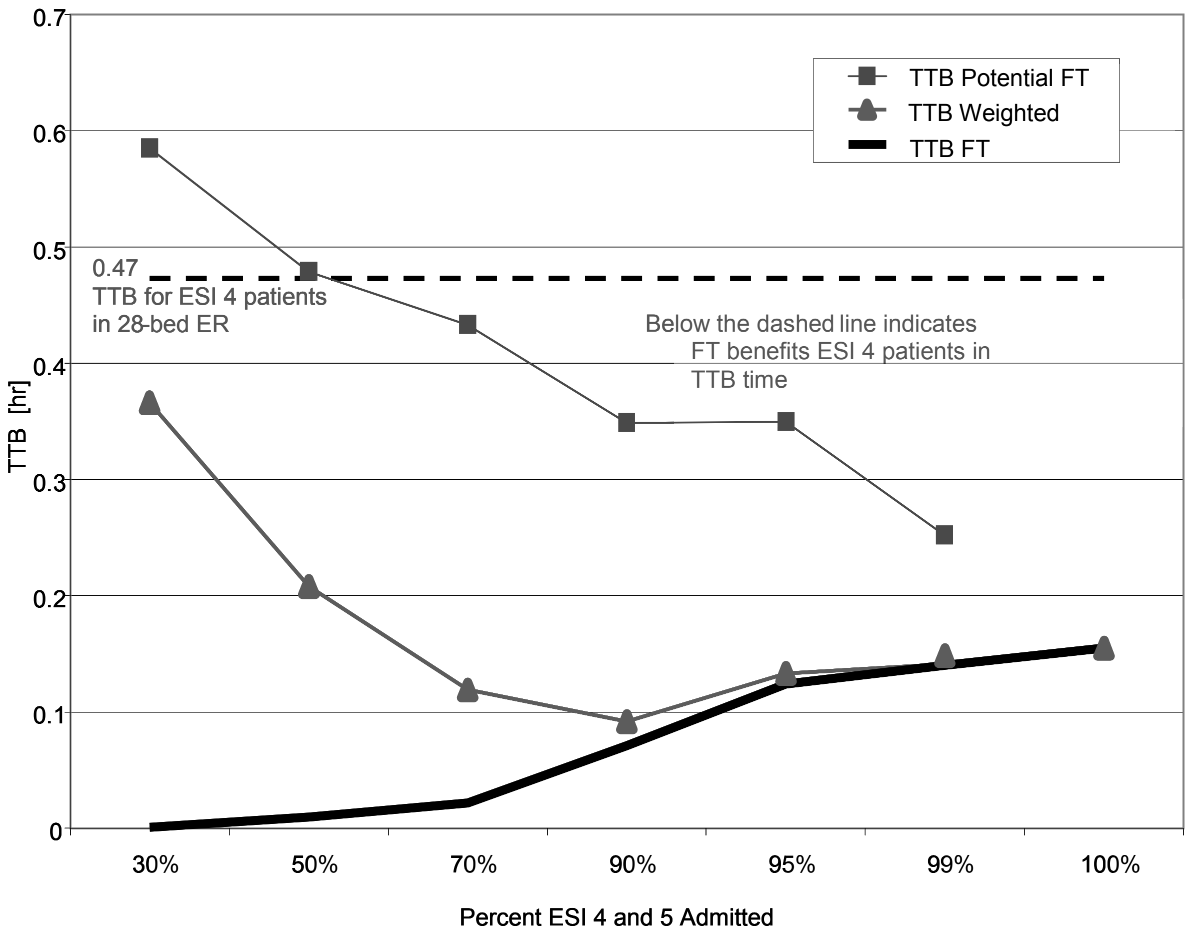


Figure 19: TTB for ESI 4 FT and potential FT patients

Despite the increase in TTB as FT usage increases, the weighted TTB always remains significantly lower than the 28 bed case represented by the dashed line. This leads to the important question of how this affects patients in the rest of the ER. Figure 20 shows the TTB for ESI 2 and 3 patients as FT usage is increased.

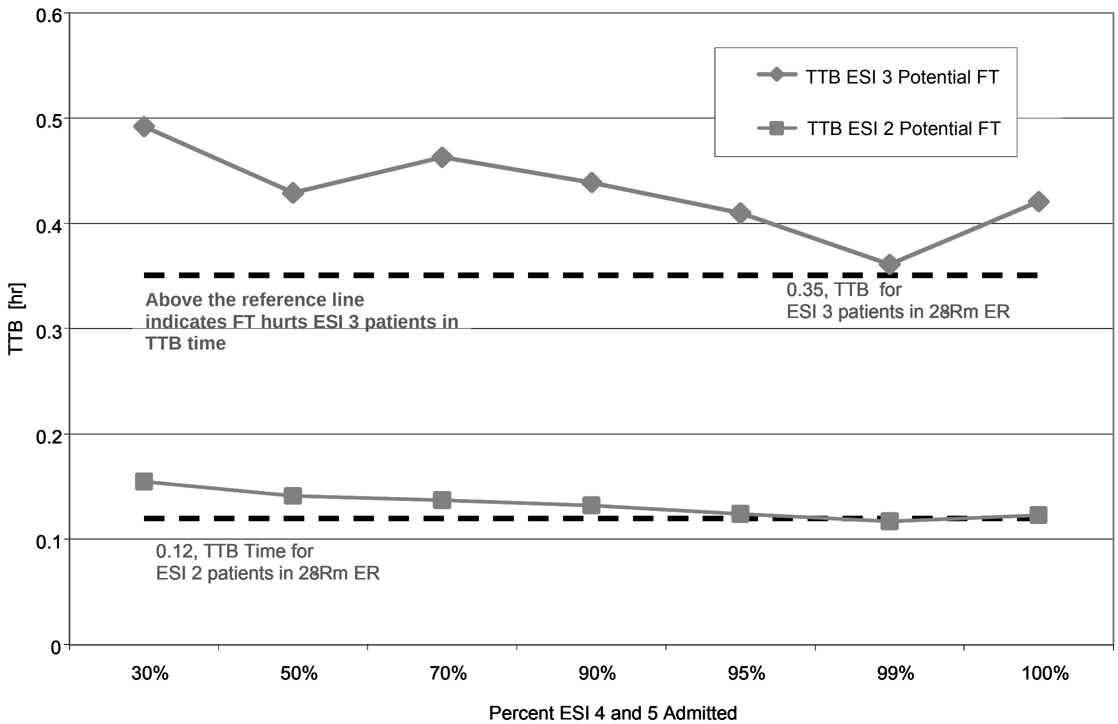


Figure 20: TTB for ESI 2 and 3 patients

As can be seen from the figure, any usage of FT seems to negatively affect ESI 3 patients. This is not surprising because in the base case there were 4 extra beds to which higher acuity patients would have priority over ESI 4 and 5 patients. Once FT is open they lose the benefit of the beds and only gain the very slight benefit of less competition for remaining beds from patients who had lower priority anyway. The slight benefit due to loss of competition manifests itself in the general downward slope of the curves. The figure suggests that although the TTB for low acuity patients is lowered due to FT, the TTB for ESI 2 and 3 patients has actually increased.

The possible remedy for this would be to allow less acute, non-IU bound, ESI 3 patients into the FT. Figure 21 shows the TTB for ESI 3 patients in the same format as was done for ESI 4 patients in Figure 19. There is a TTB for FT patients, TTB for potential FT patients, a weighted TTB curve and a line for comparison with the 28 ER bed scenario. The curve shows the same trends as Figure 19, as FT usage is increased for ESI 3 patients, the weighted TTB decreases to significantly below the base line, which means that even though the ESI 3 patients in the main ER no longer have use of the 4 extra beds, allowing some of the ESI 3 patients into the FT makes up for that loss and decreases the overall TTB.

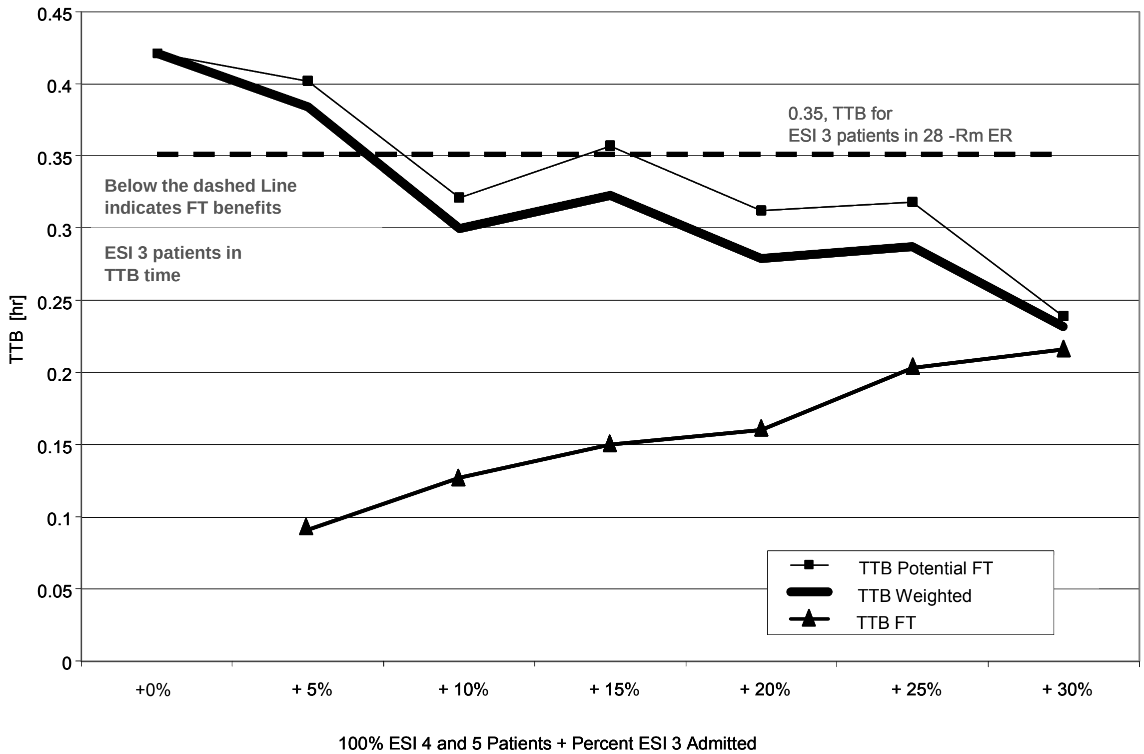


Figure 21: TTB for ESI 3 FT and potential FT patients

It is now important to study how accepting ESI 3 patients to FT effects the TTB for ESI 4 FT patients. Figure 22 has the weighted TTB for ESI 3 and 4 patients and the TTB for the base cases. From Figure 22 it can be seen that as ESI 3 patients are taken into FT the TTB for ESI 4 patients does indeed increase, however it still remains significantly lower than the base case. Therefore by accepting ESI 3 patients to FT the purpose of using FT to lower TTB for low acuity patients is still served while removing the harm to the ESI 3 patients.

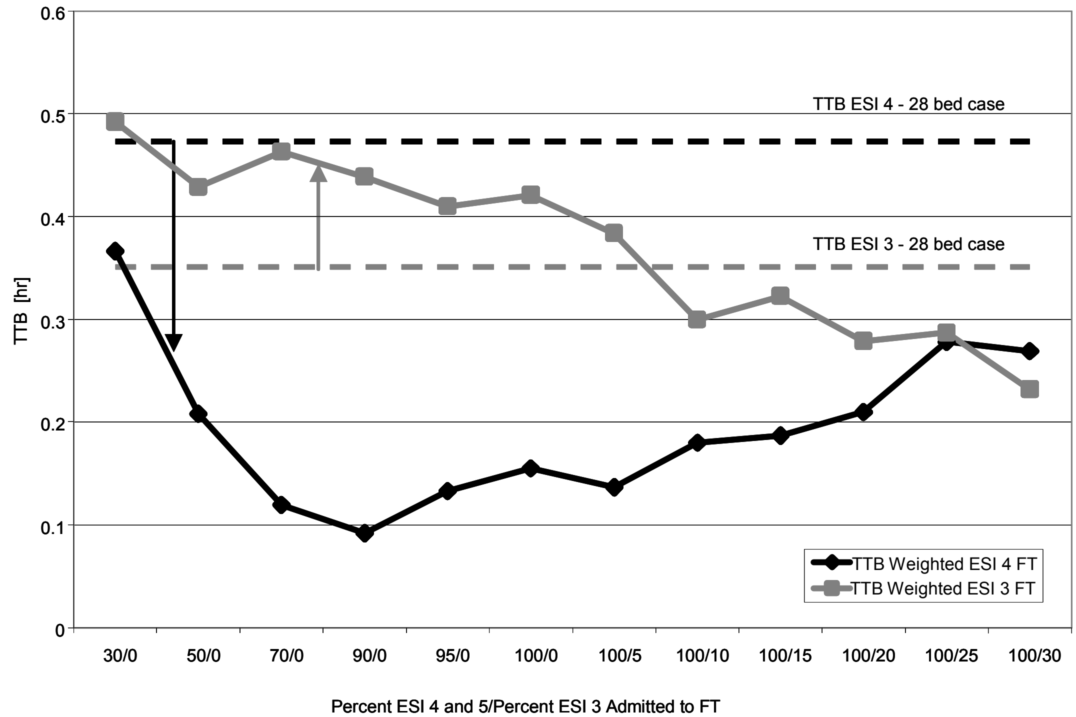


Figure 22: Weighted TTB for ESI 3 and 4 patients with increasing FT usage

The data from this experiment show that it is possible to increase utilization of FT while still serving FT's original propose and benefiting the rest of the ED patients at the same time.

4.5.3 Changing Size of FT

In the last experiment the base case was when all FT beds were used as normal ER beds, in the scenarios there was either the existence of a 4 bed FT or not. This experiment explores whether the size of FT can be adjusted so that the benefits of FT are still reached, while also gaining the benefits of having more ER beds.

As in the other experiments we begin by observing changes in throughput. Figure 23 shows the total ER/FT throughput. As can be seen in the figure there is no significant increase or decrease in throughput for any of the scenarios.

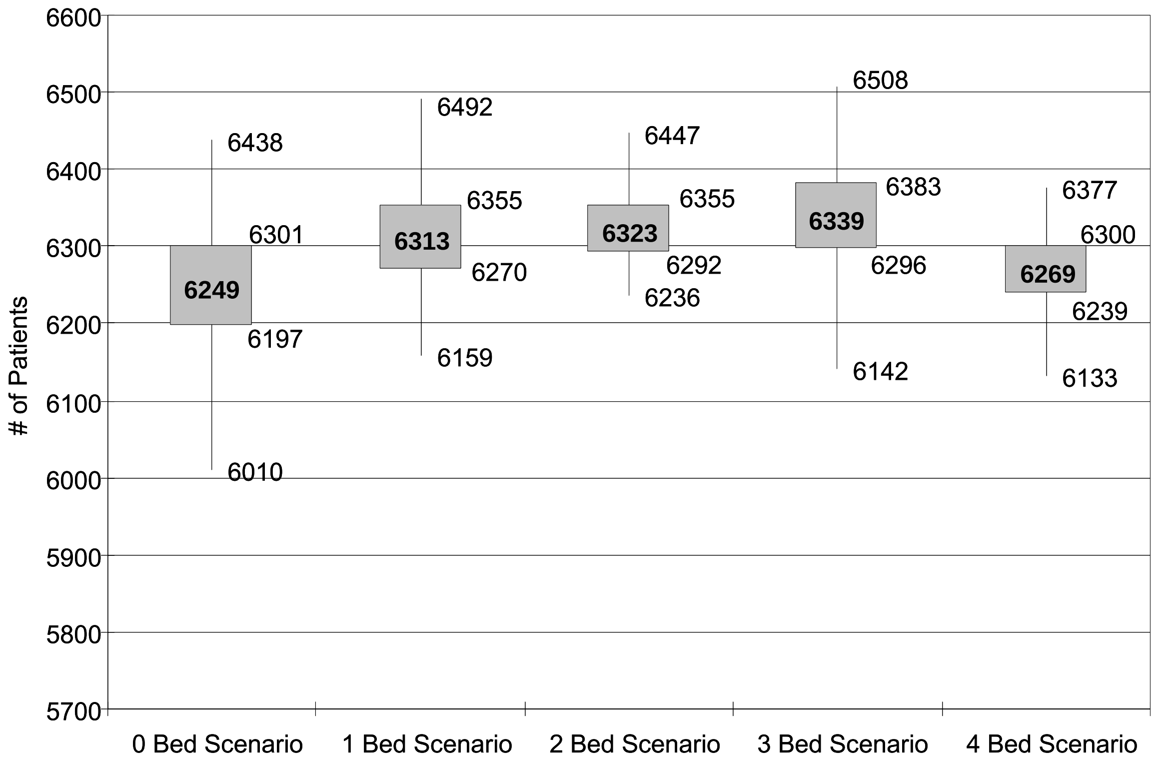


Figure 23: Total ER/FT throughput with change in FT size

The TTB for the case of 90% ESI 4 and 5 patients being accepted to FT as the number of FT rooms increases is shown in Figure 24. As can be seen, as FT beds are added, the TTB decreases.

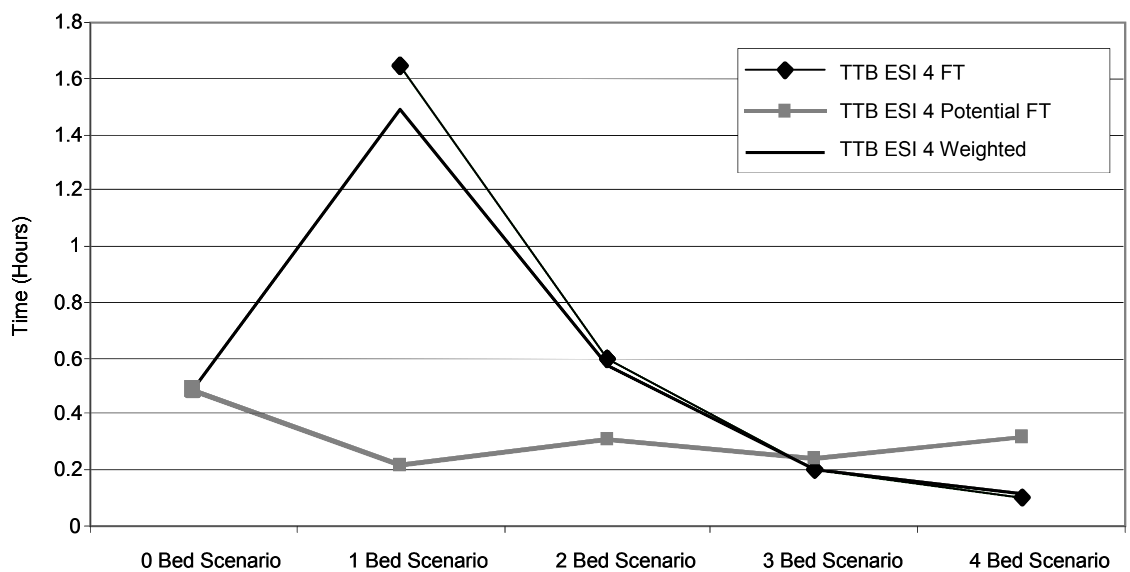


Figure 24: TTB for ESI 4 patients

The results of Figure 24 align well with our earlier results and may lead to the belief that 4 beds is indeed the best scenario. However, it is important to analyze how non-FT patients are affected. Figure 25 shows that the creation of 1 FT bed significantly helps ESI 3 patients since they have access to 3 extra beds and all the competition from low acuity patients disappears as they use the 1 FT bed. This remains the case until the 4 FT bed scenario where the extra beds for ESI 3 patients are completely gone.

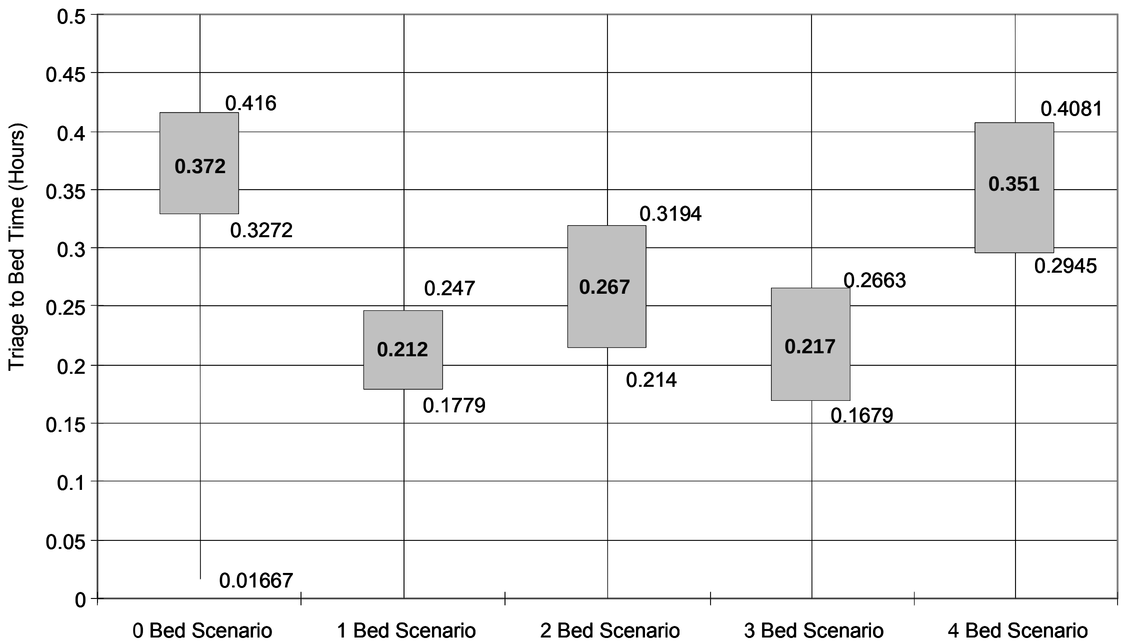


Figure 25: TTB for ESI 3 potential FT patients

Based on the figure it can be seen that although adding the fourth FT bed helps low acuity patients it works to the detriment of higher acuity patients. This means that when deciding upon the optimal set up, a judgment call must be made based on the priority of patients. This judgment may be based on the numbers of patients it affects as well as the ESI level. With that in mind, Figure 26a shows the TTB for all ESI 3 and 4 patients weighted by number of patients. It can be seen that, assuming an amount of waiting time for an ESI 3 patient is equally weighted to an amount of time for an ESI 4 patient, adding the fourth FT bed does not seem to have much of an effect. However if an ESI 3 patient's time were worth double that of an ESI 4 patient, as in Figure 26b then adding the fourth FT bed has a negative effect.

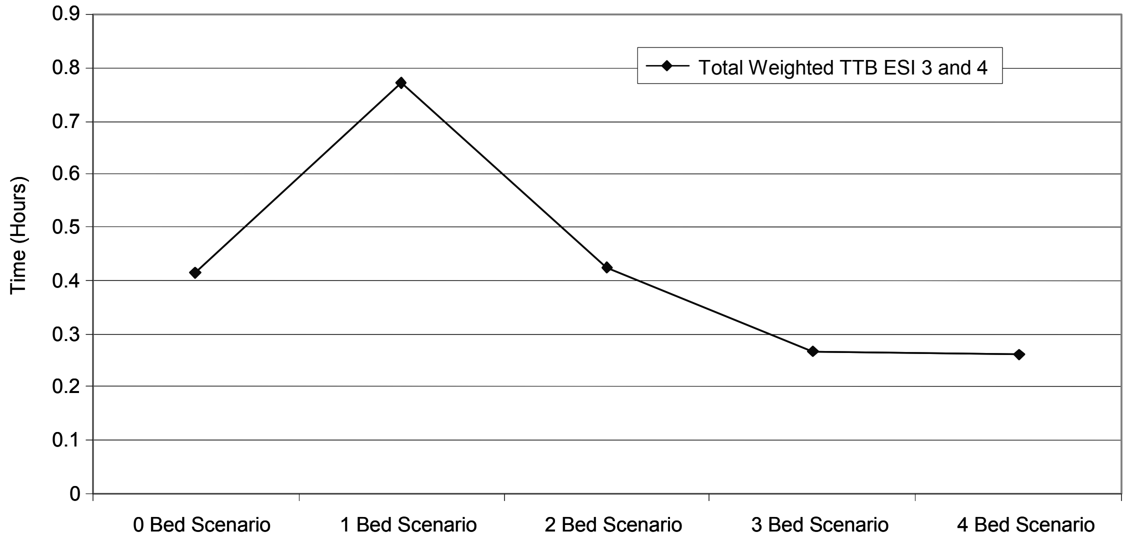


Figure 26: a) Weighted TTB for ESI 3 and 4 patients

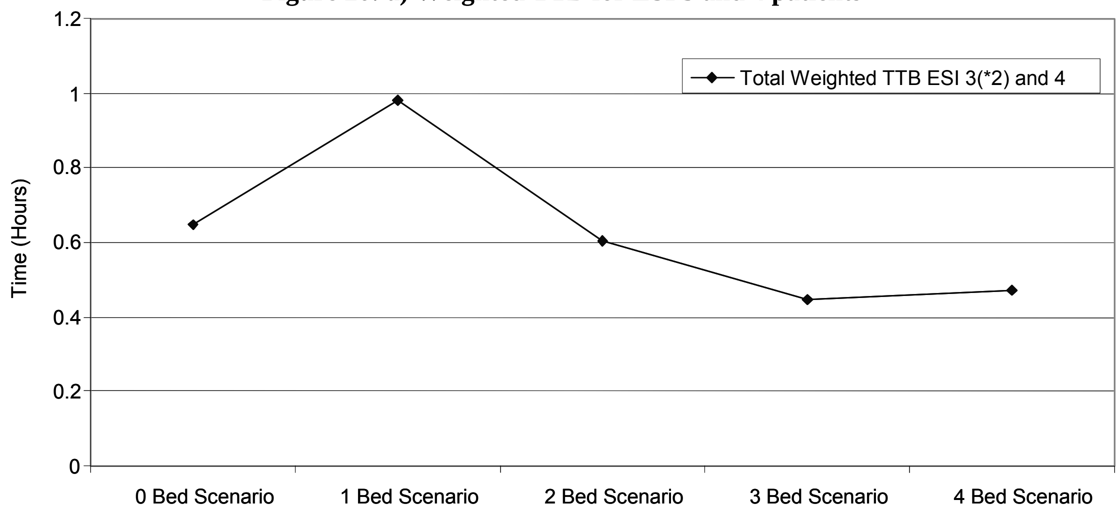


Figure 26: b) Weighted TTB for ESI 3 and 4 patients where ESI 3 time is worth twice that of ESI 4.

4.6 Case Study Conclusion

The results of this study show that there is much that can be done to improve how FT is designed and operated. Many hospitals already use FT however it is unclear whether they have studied how best to implement it. The primary results of the experiments are:

1. The FT interacts with the rest of the system and the optimal hours of operation are not when the most low acuity patients are entering the system, but when the most high acuity patients are progressing through the system.
2. It is worth taking high acuity patients into FT as long as they are not going to be transferred to the main hospital, this allows FT to avoid the boarding patient bottle neck.

3. Devoting resources to FT can be detrimental to high acuity patients and the amount of resources devoted must be considered carefully to maximize benefit to the entire ED.

The conclusions reinforce the assertion that the benefit of FT is derived from its removal of low acuity patients from the dangerous cycle caused by boarding patients. It is worth noting, that taking more patients into FT may cause a change in how patient acuity is assigned. It is possible that what we call lower acuity ESI 3 patients will become high acuity ESI 2 patients, as triage nurses begin to try and define a clear line between those who can and can't be sent to FT.

Another important concept that came out of the conclusions is how ESI 3 patients are affected by FT. FT was praised for lowering the waiting times for low acuity patients however is it really worth lowering the wait time for these patients if it is at the expense of higher acuity patients? When designing the size and use of FT a hospital administrator must have this trade off in mind.

The changing inputs experiment took ESI 3 patients into FT after sending all ESI 4 and 5 patients. However is ESI in fact the best metric for assigning patients to FT. The ED^3 identified a problem, and then simulation was used to get a sense of the solution. Now that the general idea of how to fix the design problem is known, AD can be employed once again in order to find the optimal solution, and minimize patient TTB. This is the goal of Chapter 5.

5. Redesign of FT for Optimal Patient Throughput

As mentioned in Chapter 4, it was found that the FT at our partner hospital was not used properly and that more patients should be accepted to FT in order to make the resource investment worthwhile. The experimental solution chose to accept more patients to FT by accepting all ESI 4 and 5 patients and then accepting an increasing amount of ESI 3 patients. The benefits of this can be seen in Figure 22. Although this did successfully improve the ED, the TTB improvements were not as large as would be expected from the solution to such a significant design coupling. In order to discover how to maximize FT utilization and improve patient flow even more, we decided to reapply AD, but rather than applying AD to the ED as a whole, we applied it to the mechanism that chooses patients for FT, triage.

5.1 Analyzing Triage Design

As with the creation of the ED^3 using AD, this study began with close observation. In hospital operations research practice a patient's ESI is used to predict how quickly a patient will move through an ED. Thus, the assignment of ESI 4 and 5 patients to a "Fast" track. However observation of an ED or conversations with an ED nurse will show that often the correlation between ESI and speed is not accurate. Figure 27 shows the spread of values for time in ER for each ESI, using the real data set provided by NWH described in section 3.1. The minimum of each bar is the mean minus a standard deviation and the maximum is the mean plus a standard deviation.

As can be seen in Figure 27 there are patients of ESI level 1,2 and 3 within one standard deviation of the mean value for those ESIs that take the same or even less time in an ED than ESI 4 and 5 patients. These patients move quickly through the system due to the nature of their injury, perhaps they will get transferred quickly, require fewer tests, have shorter treatment requirements, etc. When the FT is fully functional and capable of treating these patients (as is the case with our partner hospital), they can be accepted to FT and maintain unhindered flow. In section 4.5.2 it was shown that by not accepting higher acuity patients to FT despite their short treatment requirements, these higher acuity patients suffer longer TTB due to the loss of resources that they would otherwise have priority too (Figure 20). This situation is one that can have significant ethical problems.

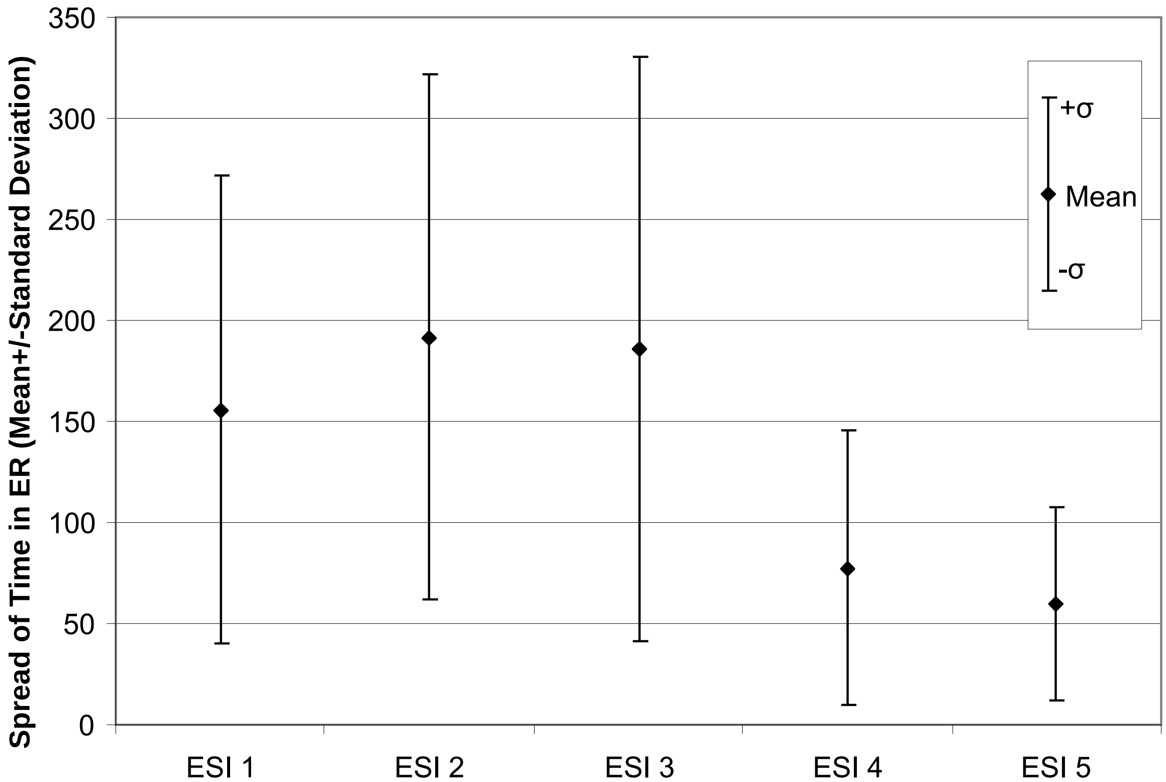


Figure 27: Time in ER by ESI level

The implications of Figure 27, is that the earlier conclusion to increase FT usage by accepting an increasing amount of ESI 3,4 and 5 patients to FT may have been a mistake. By using ESI to assign patients to FT a level of ESI 3,4 and 5 assignment may have been reached, where there were ESI 1 and 2 patients who had shorter stays in the ED, despite their higher acuity. Taking these patients into FT, rather than more ESI 3,4 and 5 patients with potentially longer stays, would further increase the utilization of FT while also maintaining the speed of FT and its independence from major bottlenecks.

The problems that are being observed from using ESI to assign patients to FT stem from the origins of triage. Triage was originally created as a method to prioritize patients based on severity of injury. It was for this purpose that ESI was created. However, triage "has evolved into an attempt to manage patients…" [Hauswald 2005], as is the case with assigning patients to FT based on triage, or more specifically based on the only design solution of triage, the ESI system. In other words modern triage has evolved two primary FRs:

FR1: Prioritize patients based on urgency

FR2: Organize patients to manage processes and flow

The DP for FR1 is the ESI system. However ED management has also been using ESI to satisfy FR2. This is a coupled design since the solution to FR1 is being used as the solution for FR2. Figure 27 verifies that this is indeed inappropriate.

The solution to this coupled design problem is a conceptually simple one; uncouple the system by making the number of DPs equal the number of FRs. The introduction of a new index that is used to identify patients based on how they will flow through the ED, we call this index, the Park Index (PI). The PI assigns a level to a patient based on their expected treatment time. Like the ESI, the PI will require iteration and practice to discover exactly how many levels are worth while and how to define these levels. In former studies it was identified that need for transfer to an inpatient unit causes an increased length of stay in the ED, therefore this would be a significant factor in assigning a PI level. Similarly the amount of tests a patient will need, how long those tests take, whether a consultant will be needed, patient factors that slow treatment (disability, age, mental state etc.) are all factors that would weigh into assigning a patients PI level. Like the ESI system, the assigning of a PI would rely heavily on the abilities of an experienced triage nurse to predict the treatment that a patient will undergo, however now rather than simply listing the treatments and converting it to resource usage, the nurse will also convert it to a time requirement.

5.2 Simulating the Park Index

Having used AD in order to discover a system design issue and then propose a solution. It is now possible to return to our DES in order to test the effectiveness of this proposed decoupling. In order to do this, a preliminary PI was proposed for the assigning patients to FT. In order to be assigned a PI, a patient must:

1. Not have the need for later admission to the IU,
2. Not be pediatric,
3. Arrive while FT is open.

From the real patient data provided by NWH, eligible patients were sorted by ESI level. Within each ESI level, patients were sorted by Time in ER, and they were assigned a PI level according to the following scale:

PI 1: 0 min < Time in ER < 30 min
PI 2: 30 min <Time in ER < 60 min
PI 3: 60 min < Time in ER < 90 min
PI 4: 90 min <Time in ER < 120 min
PI 5: 120 min < Time in ER

As in section 4.3, in the DES model, the doctor treatment time of a patient that is sent through FT is assigned according to a random distribution. The equation for that distribution is calculated using the real ED data and is dependent on ESI and the percent of patients of that ESI being sent to FT. In the earlier experiment a percentage was chosen and then the random distribution that fit that percentage was calculated and input into the model. In this study, a PI is selected. This PI corresponds to a certain percentage of patients of each ESI that will be sent to FT, and that in turn corresponds to a specific random distribution for treatment time. The FT treatment time, distribution equations for each ESI are listed in Appendix B3. Underneath each equation are tables of the distribution parameters that relate to increasing the PI level of patients of that ESI that are accepted to FT.

It is worth noting that there were no ESI 1 patients that met the criteria for PI assignment of less than 5 and therefore it was decided not to send ESI 1 patients to FT at all. This is appropriate due to the fact that in reality it is very difficult to estimate the length of stay or future needs of a patient in such an acute condition, and therefore it would be impractical to attempt to assign them a PI level at triage.

5.3 The Potential Impact of the Park Index

In order to see the potential impact of using the PI in our simulated ED, we input the treatment time distribution data, described above, into the Arena Process Analyzer, which has been described in section 3.2. To evaluate the impact of changes this study used the same metrics that were implemented in Chapter 5: Patient Throughput and TTB. Four possible scenarios were considered. These scenarios were for the acceptance of all PI1, PI 1-2, PI 1-3 and PI 1-4 patients to FT.

Figure 28 is the total FT throughput broken down by ESI level for each scenario. There is also a line which shows the value of throughput that was measured in the best case scenario in section 4.5.2 where 100/100/25% ESI 5/4/3 patients were sent to the FT, respectively. As can be seen in the figure, the former best case actually sent more patients through FT than any of the PI usage scenarios.

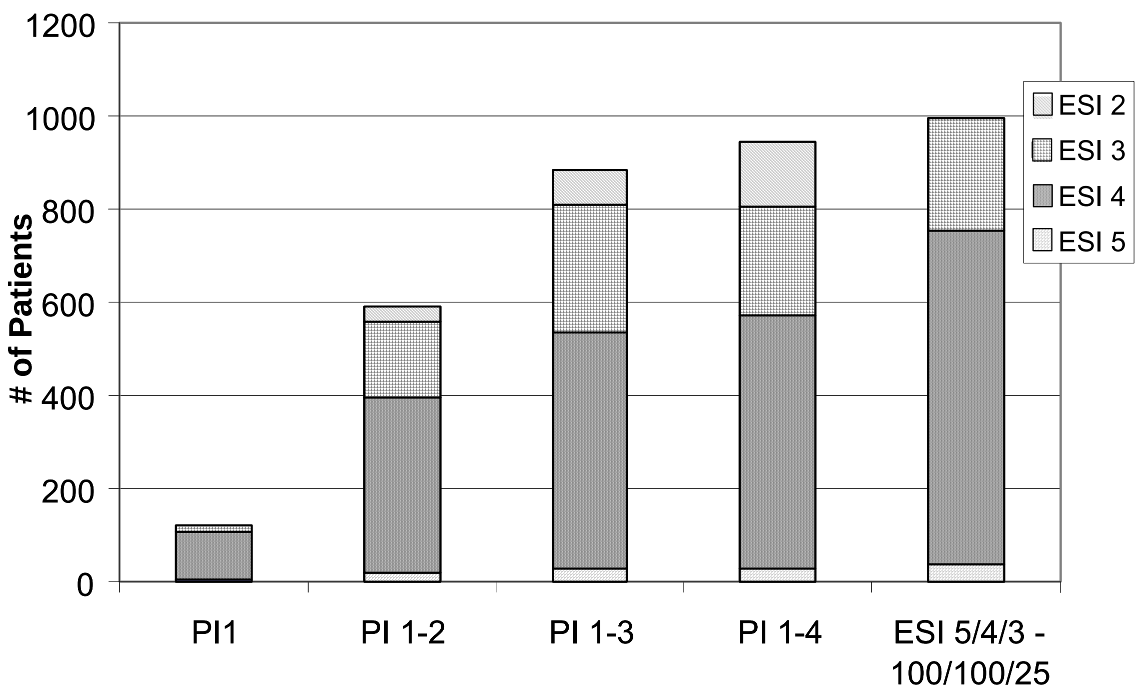


Figure 28: FT throughput with increasing PI based FT usage

Although the results from Figure 28 show that FT throughput has decreased from use of the PI, it can also be seen that the PI scenarios send a significant amount of ESI 2 patients to FT that would have otherwise been in the main ER. It is therefore worth looking at the change in relevant main ER throughput, shown in Figure 29, due to the use of the PI. As in section 4.5, relevant throughput includes all patients in the main ER who are not bound for the IU and all FT patients.

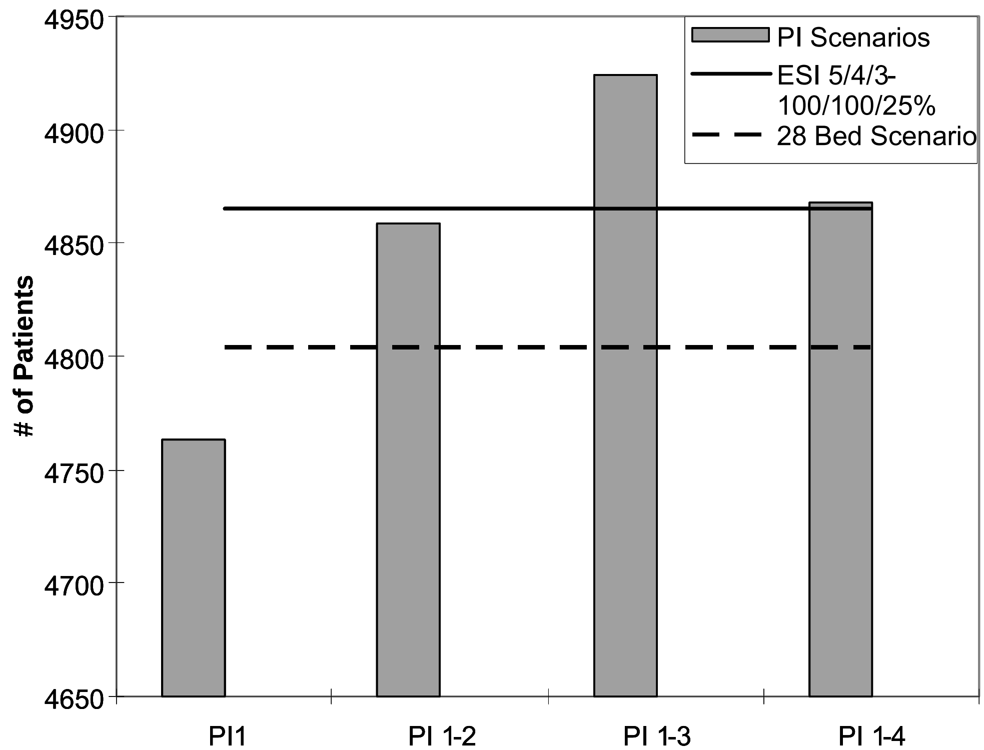


Figure 29: Total Relevant ER Throughput

As can be seen from Figure 29, although the use of PI did not generate as much FT throughput as the former best case it did show potential for a significant increase in total relevant ER throughput over that case and the 28 bed scenario. This improvement in relevant ER throughput means that removing some ESI 2 patients from competition in the main ED by placing them in FT has significant benefits for the whole system. Since there is a limited amount of patients that are set to enter the ED, this increase in ED throughput implies a decrease in LWBS patients and a decrease in ambulance diversion time.

As before, although it is useful to look at throughput to get a sense of how changes in FT assignment affect the system, it is more important, from an administrative standpoint, to see how a change in FT policy affects TTB. To do this, we will once again look at how the weighted average TTB changes. Figure 30 shows the percent difference between the weighted TTB of the section 4.5.2 best case scenario and the weighted TTB for the specific PI usage scenario for each ESI. The figure also shows a weighted total TTB difference across all ESIs.

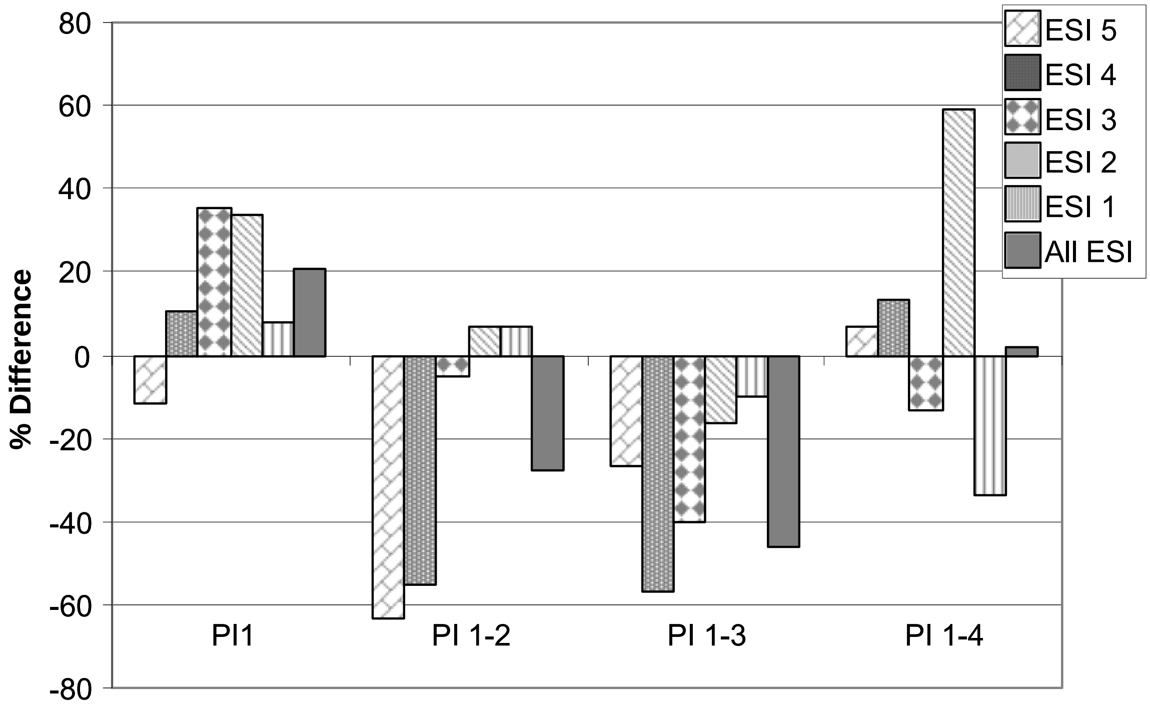


Figure 30: Percent difference between TTB ESI 5/4/3 100/100/25% scenario and PI scenario

The values for the percent change in TTB across ESIs between the PI scenarios and the section 4.5.2 best case scenario are:

PI 1: 21%

PI 1-2: -28%

PI 1-3: -46%

PI 1-4: 2%

Although both the assignment of PI 1-2 and PI 1-3 to FT show an overall improvement in TTB, it is important to note that only PI 1-3 has a TTB improvement for each ESI level.

5.4 Redesign of FT for Optimal Patient Throughput - Conclusion

Triage has developed in today's EDs as a method of sorting patients based on how quickly they need to be seen, but also as a way of managing patient flow. The system used to sort patients based on urgency is called the ESI system. However this system does not take patient flow needs into account when assigning levels. Therefore when using the ESI system to try and facilitate patient flow, its original purpose may suffer due to a coupled design. This exact situation was observed when the ESI system was used to assign patients to FT. The low acuity patients received quicker service while middle acuity patients suffered a loss of available resources.

In order to allow triage to satisfy the need for prioritizing based on acuity and the need to facilitate flow, AD was applied. The use of AD led to the creation of a new index based on how long a patient is likely to remain in the ED, called the PI. In order to test that this new index would improve patient flow, PI levels were assigned retrospectively to real patient data, and this was used to find parameters to enter into the DES.

The results of the simulation showed that use of the PI when assigning patients to FT, is associated with a significant increase in total relevant patient throughput as well as a decrease in the amount of time that a patient must wait for a bed as compared to even the best case scenario that had been identified in Chapter 4. Chapter 4 has shown the effectiveness of using AD and DES to identify high level problems and suggest general solutions to those problems. This chapter showed that once the high level problems are identified, the same manufacturing systems methods can be used once again but at a more detailed level, to find a more accurate solution to the original problem.

It is important to note that although the simulated scenarios show that the optimal usage of FT is at a PI level of 1-3 this may not be the case in real-life usage of a PI-like system. There may be a point in-between PI 1-3 and PI 1-4 that is in fact the optimal solution. Also, since PI 1 and PI 1-2 have no significant effect, it may not be worth having a system broken down by every half hour. Instead, real life implementations may find that it is most useful to only have a three point system with PI levels based on hour increments or even 1.5 hour increments.

Although in this case PI was only used for assigning FT it may be used for other applications in the ED. For example it may be worth while to create multiple different tracks rather than just FT and main ER. Then the PI can be used to assign patients to each of these different tracks. In the end, the universal conclusion of this study is that AD justifies the use of another index and that this index has potential for great improvements to ED patient flow.

6. Conclusion/Future Work

The field of healthcare is evolving. The days when a doctor had time to pay individual house calls to a patient and carried all that they needed in a small black bag are gone. Now doctors can not afford the time to make personal trips, in fact they are often restricted in how much time they are permitted to spend with a single patient on site. This is all due to the ever increasing demand for faster, higher quality, yet cheaper service. This increasing demand without a proportional increase in supply is causing a great deal of crowding in EDs. This crowding threatens the ability of EDs to continue to act as the safety nets for our healthcare system.

In the competitive world of manufacturing systems, research has been performed to discover new ways of operating more efficiently. Although in many respects healthcare systems reflect manufacturing systems, such as the ED, the adoption of manufacturing systems methods has been slow. The reasons for this slow adoption have been discussed; they are social, economic, political, as well as systematic. With the many obstacles to using manufacturing systems methods in the healthcare setting many are left to wonder whether it is in fact worth attempting. This thesis selected specific manufacturing systems techniques and applied them to an ED to show that this action had potential benefits.

Using AD it was possible to analyze the ED system and highlight design issues/couplings. Many of these couplings may have already been known intuitively by those who work in the field however with the detailed functional decomposition it is easy to fully understand the interactions that form the coupling, which facilitates communication about the issue as well as the invention of ways to eliminate or alleviate the problem.

Once AD was used to identify an area to focus attention in the ED, it was then possible to use another manufacturing system method, DES. After creating a detailed simulation of the ED a series of experiments were performed that formed high level actionable conclusions for improving patient flow in the ED through the more efficient use of FT. These conclusions were only discovered when applying manufacturing systems methods. Without these methods, hospital managers would continue to add resources in parts of the system, such as FT, without fully understanding how to best invest these resources.

Having used AD and DES to identify high level improvements that can be made to the ED, the methods were used once again on a more detailed level to further refine these conclusions. This showed that the methods are useful on all levels of the ED system and also showed the potential for great improvement thanks the reiteration of the methods.

The application of two manufacturing systems methods has already yielded useful results for an ED. This result shows that it is indeed appropriate to apply manufacturing methods to an ED, however this must be done with the knowledge of the differences between healthcare and manufacturing. Due to the differences it may not be possible to completely decouple a healthcare system using AD. Similarly when using DES there are often assumptions that are made about resources that get more complicated when dealing with humans rather than machines and products. That is why it is important to note that the detailed results of the performed experiments may not be as important as the general conclusions. In other words, it would be a mistake to claim that the optimal patient input to FT found in Chapters 4 and 5 are in fact the optimal input in real life. The real result is that more patients must be taken into FT and how that is done may vary. This means that manufacturing systems methods are applicable to ED systems, however the shortcomings of the methods must be considered during actual implementation.

Future work on this subject should include the application of the results from Chapters 4 and 5 in the real ED. This would provide a study of how these hypothetical improvements must be altered in order to be implemented in real life. This study would expose the differences between manufacturing, real EDs and simulated EDs. It would also prove in more certain terms that the suggestions, derived from manufacturing systems, are indeed legitimate for improving the ED. Finally while the conclusions from this thesis are being tested in the real life settings, the methods proposed should be used on the high level once again in order to find other design problems and solutions in the ED and the hospital as a whole.

Appendices

A. Complete Functional Decomposition of Emergency Department: The Emergency Department Design Decomposition ED^3

A.1 FR0 - Sustainable Operations of the ED

- [FR0] Sustainable Efficient Operations of the Emergency Department
- [DP0] Design for Sustainable Efficient operation

A.2 ED^3 FR1 - Quality

- [FR1] Provide quality clinical treatment (decisions and implementations)
- [DP1] Quality, Staff and Processes
    - [FR1.1] Staff generate quality decisions
    - [DP1.1] Quality medical decision making Staff with correct information
        - [FR1.1.1] Maintenance of Staff competent at making decisions
        - [DP1.1.1] Acquiring intelligent staff and continued education
            - [FR1.1.1.1] Hiring competent Staff
            - [DP1.1.1.1] Hiring Practices
                - [FR1.1.1.1.1] Hiring of Doctors who meet standards
                - [DP1.1.1.1.1] Hire Based on Doctor Standards
                - [FR1.1.1.1.2] Hiring Nurses who meet standards
                - [DP1.1.1.1.2] Hire based on Nursing Standards
                - [FR1.1.1.1.3] Hiring of administrative staff who meet standards
                - [DP1.1.1.1.3] Hire Based on administrative staff standards
            - [FR1.1.1.2] Staff is aware of a diversity of current knowledge and practices
            - [DP1.1.1.2] Diversity of staff /Continued Education
                - [FR1.1.1.2.1] Required Licenses are maintained
                - [DP1.1.1.2.1] Licensing Courses
                - [FR1.1.1.2.2] Current knowledge and practices are accessible
                - [DP1.1.1.2.2] Training Courses/Research time
                - [FR1.1.1.2.3] Maintain ability to consult with experts
                - [DP1.1.1.2.3] Have ability to talk to an expert or send patient to expert
            - [FR1.1.1.3] State of Mind is Un-compromised
            - [DP1.1.1.3] Minimize Stress on Employees
                - [FR1.1.1.3.1] Stress from environment and interactions is minimized
                - [DP1.1.1.3.1] Low stress ED design, stress relief practices
                    - [FR1.1.1.3.1.1] Stress from working with patients is minimized
                    - [DP1.1.1.3.1.1] Keep Patients happy

        - [FR1.1.1.3.1.2] Stress from interaction between colleagues is minimized
        - [FR1.1.1.3.1.3] Stress from crowded conditions is minimized
      - [FR1.1.1.3.2] Staff fatigue is minimized
      - [DP1.1.1.3.2] Work In shifts
        - [FR1.1.1.3.2.1] Mental Fatigue is minimized
        - [FR1.1.1.3.2.2] Physical Fatigue is minimized
- [FR1.1.2] Timely dissemination of accurate patient information
- [DP1.1.2] Clear Patient Information distribution system
  - [FR1.1.2.1] Provide clear understanding of necessary action for transferring information
  - [DP1.1.2.1] Standard Patient information transfer Procedures
    - [FR1.1.2.1.1] Have standard procedures for inputting information
    - [DP1.1.2.1.1] Timing Procedures, information collection standards
    - [FR1.1.2.1.2] Have Standard Procedure for retrieving data
    - [DP1.1.2.1.2] Timing procedures for accessing necessary data
  - [FR1.1.2.2] Information on patients is readily available
  - [DP1.1.2.2] Information is stored and accessible in real time
    - [FR1.1.2.2.1] Ensure that staff knows where to store information so that it can be immediately accessed
    - [DP1.1.2.2.1] Information storage software
    - [FR1.1.2.2.2] Ensure that staff knows where to retrieve information that is up to date
    - [DP1.1.2.2.2] Information access software
  - [FR1.1.2.3] good communication culture
  - [DP1.1.2.3] Communications Training
    - [FR1.1.2.3.1] Ensure No information confusion
    - [DP1.1.2.3.1] Standard format for information documentation
    - [FR1.1.2.3.2] Ensure that all staff understand one another
    - [DP1.1.2.3.2] Education on common terminology
    - [FR1.1.2.3.3] Ensure staff is comfortable exchanging information
    - [DP1.1.2.3.3] Communications training sessions, social activities
- [FR1.1.3] Maintain functionality and access to testing facilities
- [DP1.1.3] Facility Maintenance and Design Planning
  - [FR1.1.3.1] Analysis Equipment works to design specifications
  - [DP1.1.3.1] Equipment Maintenance
    - [FR1.1.3.1.1] Equipment is regularly maintained
    - [DP1.1.3.1.1] Maintenance crews
    - [FR1.1.3.1.2] Emergency errors can be addressed
    - [DP1.1.3.1.2] Redundant Machinery, on call maintenance crews

            - [FR1.1.3.2] Analysis Equipment is accessible
            - [DP1.1.3.2] Design for best use of space
                - [FR1.1.3.2.1] Regularly used analysis equipment is near by and easily accessible
                - [DP1.1.3.2.1] Standard equip is in rooms, other important equipment is in ED
                - [FR1.1.3.2.2] Irregular Equipment is accessible
                - [DP1.1.3.2.2] ability to use equipment in hospital
- [FR1.2] Staff Implement proper treatment
- [DP1.2] Quality Procedures with correct information
    - [FR1.2.1] Accurate response to decisions
    - [DP1.2.1] Attentive Staff with clear responsibilities
        - [FR1.2.1.1] responsibilities of staff are clear
        - [DP1.2.1.1] Defined Jobs
            - [FR1.2.1.1.1] Staff member is aware of their jobs and each others and who they answer too
            - [DP1.2.1.1.1] Defined Contracts/Labeled Staff
            - [FR1.2.1.1.2] Staff member is aware of the requirements of their job
            - [DP1.2.1.1.2] Rigorous Training understanding of command structure
        - [FR1.2.1.2] Maintain standard operating procedures
        - [DP1.2.1.2] Procedures for how to perform a treatment are known to the staff member
            - [FR1.2.1.2.1] Staff members are aware of treatment procedures
            - [DP1.2.1.2.1] Training in treatment procedures
            - [FR1.2.1.2.2] Failure to perform procedure is noticed and corrected
            - [DP1.2.1.2.2] Oversight, complaint filing
    - [FR1.2.2] Timely dissemination of decisions
    - [DP1.2.2] Decision Information distribution system
        - [FR1.2.2.1] decisions are made available quickly to all involved
        - [DP1.2.2.1] Decisions transition
            - [FR1.2.2.1.1] Decisions are sent to lab technicians
            - [DP1.2.2.1.1] quick test transmission system
            - [FR1.2.2.1.2] Decisions are given to others who need to perform action
        - [FR1.2.2.2] Decision makers are clear on what decision information needs to be given
        - [DP1.2.2.2] Standard formats/awareness of others capabilities
            - [FR1.2.2.2.1] maintain decision maker awareness of treatment parameters
            - [DP1.2.2.2.1] training for treatment methods
            - [FR1.2.2.2.2] Maintain ability to clearly list parameters
            - [DP1.2.2.2.2] Forms for decision requirements
        - [FR1.2.2.3] Information on Decisions is readily available

            - [DP1.2.2.3] Information is stored and accessible in real time
                - [FR1.2.2.3.1] Ensure that staff knows where to store information so that it can be immediately accessed
                - [DP1.2.2.3.1] Information storage software
                - [FR1.2.2.3.2] Ensure that staff knows where to retrieve information that is up to date
                - [DP1.2.2.3.2] Information access software
        - [FR1.2.3] Maintain Functionality of and access to treatment facilities
        - [DP1.2.3] Maintenance and planning
            - [FR1.2.3.1] Treatment Equipment works to design specifications
            - [DP1.2.3.1] Maintenance
                - [FR1.2.3.1.1] Equipment is regularly maintained
                - [DP1.2.3.1.1] Maintenance crews
                - [FR1.2.3.1.2] Equipment errors can be addressed
                - [DP1.2.3.1.2] Redundant Machinery, on call maintenance crews
            - [FR1.2.3.2] Treatment Equipment is Accessible
            - [DP1.2.3.2] Design for best use of space
                - [FR1.2.3.2.1] Regularly used treatment equipment is accessible
                - [DP1.2.3.2.1] Standard treatment equipment in rooms or located in ED
                - [FR1.2.3.2.2] Irregular Equipment is accessible
                - [DP1.2.3.2.2] located in hospital with specialty departments
    - [FR1.3] Ensure problems are fixed through feedback/review
    - [DP1.3] Feedback/review mechanism (e.g. on-the-spot vs. lessons-learned, unrestricted upward feedback, constructive feedback/review vs. discipline-oriented)
        - [FR1.3.1] communication is encouraged
        - [DP1.3.1] communication tools and guidelines
        - [FR1.3.2] communication skills are developed
        - [DP1.3.2] training evaluation
            - [FR1.3.2.1] Good manners are promoted
            - [FR1.3.2.2] Ability to express thoughts
            - [FR1.3.2.3] Ability to listen to others

A.3 ED^3 FR2 - Satisfaction

- [FR2] satisfy all involved parties
- [DP2] ED design and operation includes Satisfaction Providers
    - [FR2.1] Maintain satisfaction of all internal parties
    - [DP2.1] Make staff satisfaction providers available
        - [FR2.1.1] Employees are given competitive salaries/compensation
        - [DP2.1.1] Pay employees based on workload and education
            - [FR2.1.1.1] Be aware of competitive offerings
            - [DP2.1.1.1] Research Other Hospitals
                - [FR2.1.1.1.1] Competitor salaries have been researched and are documented

        - [DP2.1.1.1.1] Human Resources Study
        - [FR2.1.1.1.2] Be aware of area issues
        - [DP2.1.1.1.2] Be aware of local cost of living as well as area benefits
        - [FR2.1.1.1.3] Be aware of other possible forms of compensation
        - [DP2.1.1.1.3] Human Resources study
    - [FR2.1.1.2] Pay employees
    - [DP2.1.1.2] Have income that can be used to pay employees
        - [FR2.1.1.2.1] Maximize Patient Revenue
        - [DP2.1.1.2.1] Operations to maximize revenue
        - [FR2.1.1.2.2] Minimize Cost
        - [DP2.1.1.2.2] Operations at minimum cost
        - [FR2.1.1.2.3] Maximize government revenue
        - [DP2.1.1.2.3] Government Grants/Taxes?
    - [FR2.1.1.3] Be capable of offering compensation even with low funds
    - [DP2.1.1.3] Provide healthcare/ other benefits
        - [FR2.1.1.3.1] Offer other forms of compensation
        - [DP2.1.1.3.1] Food vouchers
- [FR2.1.2] Distribute the employee work load evenly
- [DP2.1.2] Balanced Time Schedules
    - [FR2.1.2.1] Achieve optimum staff/patient ratio
    - [DP2.1.2.1] Study past trends to schedule for future and be able to improvise based on situation
        - [FR2.1.2.1.1] Be prepared for "normal" demand
        - [DP2.1.2.1.1] Regular schedule based on normal demands
        - [FR2.1.2.1.2] Be prepared for abnormal demand
        - [DP2.1.2.1.2] On call scheduling staff
    - [FR2.1.2.2] Employees are given responsibilities based on current work load. (Understand work requirements)
    - [DP2.1.2.2] Categorize injuries/Types of Patients
        - [FR2.1.2.2.1] Types of patients/injuries are categorized
        - [DP2.1.2.2.1] Coloring system
        - [FR2.1.2.2.2] Work can be distributed amongst nurses
        - [DP2.1.2.2.2] Charge Nurse
    - [FR2.1.2.3] Be able to track load
    - [DP2.1.2.3] Employee assignments are posted
        - [FR2.1.2.3.1] Be aware of what nurse is with what patient
        - [DP2.1.2.3.1] Tracking system
        - [FR2.1.2.3.2] Be aware of how many patients each employee has
        - [DP2.1.2.3.2] Tracking System
        - [FR2.1.2.3.3] Make know data available to decision makers
        - [DP2.1.2.3.3] Accessible Tracking System
- [FR2.1.3] Hospital Success creates employee satisfaction
- [DP2.1.3] Promote feeling of ownership (autonomy)

        - [FR2.1.3.1] Employees have personal stake in hospital success
        - [DP2.1.3.1] Success Bonuses/Positive reinforcement
            - [FR2.1.3.1.1] Be capable of tracking success
            - [DP2.1.3.1.1] success metrics
            - [FR2.1.3.1.2] Be capable of tracking each employees contribution to success
            - [DP2.1.3.1.2] evaluations
        - [FR2.1.3.2] Have personal control over quality without fear of excessive punishment
        - [DP2.1.3.2] Methods of feedback, tracking of responsibility
            - [FR2.1.3.2.1] Provide understanding of acceptable mistakes
            - [DP2.1.3.2.1] List of acceptable mistakes and mistakes that deserve punishment
            - [FR2.1.3.2.2] Provide understanding of consequences
            - [DP2.1.3.2.2] Hospital policy
            - [FR2.1.3.2.3] Have method of reporting own mistakes
            - [DP2.1.3.2.3] computer reporting system
            - [FR2.1.3.2.4] Have method of reporting others mistakes
            - [DP2.1.3.2.4] Anonymous computer reporting system
- [FR2.2] Satisfy patients and guests
- [DP2.2] Swift visit with convenient access to objects of physical and mental comfort
    - [FR2.2.1] comfort of patients and support is provided
    - [DP2.2.1] objects of physical and mental comfort
        - [FR2.2.1.1] Physical Comfort is provided
        - [DP2.2.1.1] Design furniture for physical comfort
            - [FR2.2.1.1.1] Furniture designed for comfort
            - [DP2.2.1.1.1] Padded, Ergonomic?
            - [FR2.2.1.1.2] Rooms are decorated for comfort
            - [DP2.2.1.1.2] soft colors, smooth edges, wall decoration
            - [FR2.2.1.1.3] Convenient access to sustenance
            - [DP2.2.1.1.3] Available cafe, snack machines, drink machines, water fountain
            - [FR2.2.1.1.4] Environment is controlled
            - [DP2.2.1.1.4] Disinfectants, temp, humidity, light
                - [FR2.2.1.1.4.1] Temperature is controlled
                - [FR2.2.1.1.4.2] Airflow is controlled
                - [FR2.2.1.1.4.3] Humidity is controlled
                - [FR2.2.1.1.4.4] Illumination levels and spectrum are controlled
        - [FR2.2.1.2] Mental Comfort
        - [DP2.2.1.2] Design for Mental Comfort
            - [FR2.2.1.2.1] Privacy is offered
            - [DP2.2.1.2.1] Separate rooms or curtains
            - [FR2.2.1.2.2] Patients and guests feel appreciated
            - [DP2.2.1.2.2] Employee attitude
            - [FR2.2.1.2.3] distractions are offered

            - [DP2.2.1.2.3] Provide Media
            - [FR2.2.1.2.4] Spiritual Comfort is offered
            - [DP2.2.1.2.4] Praying Room/priest
        - [FR2.2.1.3] Convenience of ED use
        - [DP2.2.1.3] Location and design for patient convenience
            - [FR2.2.1.3.1] External Access to ED
            - [DP2.2.1.3.1] Front doors
            - [FR2.2.1.3.2] Proper facilities are provided
            - [DP2.2.1.3.2] Bathrooms/Waiting rooms/telephone
            - [FR2.2.1.3.3] Cleanliness of facilities is maintained
            - [DP2.2.1.3.3] Cleaning staff and standards
            - [FR2.2.1.3.4] Location of Facilities within the ED
            - [DP2.2.1.3.4] All in obvious places with good signage
            - [FR2.2.1.3.5] ED is easily navigate able
            - [DP2.2.1.3.5] good signage and directions
    - [FR2.2.2] Patients less aware of non action time (wait time)
    - [DP2.2.2] Design for less noticeable wait time
        - [FR2.2.2.1] Wait time is reduced
        - [DP2.2.2.1] Efficient Processes with lower wait time
            - [FR2.2.2.1.1] wait time till receiving the very first care/examination is reduced
            - [FR2.2.2.1.2] time for waiting to be admitted to diagnosis and treatment area is reduced
            - [FR2.2.2.1.3] time for waiting in between diagnosis and treatment steps is reduced
            - [FR2.2.2.1.4] time after diagnosis and treatment until discharge is reduced
        - [FR2.2.2.2] Patient does not notice wait time
        - [DP2.2.2.2] Engage patient, keep up dated
            - [FR2.2.2.2.1] Have methods of engaging patient
            - [DP2.2.2.2.1] volunteers, status updates

A.4 ED^3 FR3 - Safety

- [FR3] Parties are safe from receiving new injuries or diseases through the prevention or immediate response to health hazards [DP3] Safety Measures
    - [FR3.1] Prevention of hazards
    - [DP3.1] Hazard prevention rules
        - [FR3.1.1] All Parties are aware of potential hazards
        - [DP3.1.1] Safety classes
            - [FR3.1.1.1] Educated in common dangers
            - [DP3.1.1.1] Teach new employees
            - [FR3.1.1.2] safety hazards are reported
            - [FR3.1.1.3] Safety hazards are advertised
            - [DP3.1.1.3] Signs and Labels
        - [FR3.1.2] probability of accidents due to operations is minimized

        - [DP3.1.2] trained users and limited dangerous objects
            - [FR3.1.2.1] Accidents during diagnostics and treatment are avoided
            - [DP3.1.2.1] Only Allow trained users
                - [FR3.1.2.1.1] Staff remains Focused
                - [DP3.1.2.1.1] Minimize Distraction
                    - [FR3.1.2.1.1.1] distractions are minimized
                    - [FR3.1.2.1.1.2] Staff physical status is maintained
                    - [FR3.1.2.1.1.3] Staff Mental Status is maintained
                - [FR3.1.2.1.2] Staff are trained in equipment usage
            - [FR3.1.2.2] Accidents due to motion are avoided
            - [DP3.1.2.2] Design User areas to reduce crowding
                - [FR3.1.2.2.1] Movement is minimized
                - [DP3.1.2.2.1] Make tools easily accessible
                - [FR3.1.2.2.2] pathways a clear
                - [FR3.1.2.2.3] exposure to dangerous equipment is minimized
            - [FR3.1.2.3] Accidents during latency
                - [FR3.1.2.3.1] exposure to dangerous equipment is minimized
                - [FR3.1.2.3.2] equipment in waiting and working area is secure
        - [FR3.1.3] Physical Environment is clear of contaminants
        - [DP3.1.3] Cleaning supplies and staff
            - [FR3.1.3.1] Physical environment clean
            - [FR3.1.3.2] Physical environment is disease free
    - [FR3.2] damages are reported
    - [DP3.2] system for reporting damages
    - [FR3.3] Capable of responding to accidents
    - [DP3.3] Equipment and procedures for responding to accidents
        - [FR3.3.1] First Responder is designated
        - [DP3.3.1] Person in command
        - [FR3.3.2] Hazard is Contained
        - [DP3.3.2] Zoning
        - [FR3.3.3] injuries and diseases are treated
        - [DP3.3.3] Have access to first aid supplies

A.5 ED^3 FR4 - Access

- [FR4] Optimize System Flow
- [DP4] Design for control of inputs and throughput
    - [FR4.1] Manage Inputs
    - [DP4.1] Attractive facilities with patient acceptance controls
        - [FR4.1.1] Known Attractiveness of hospital to potential patients is maintained
        - [DP4.1.1] Quality of Hospital and advertisement
            - [FR4.1.1.1] Make quality of hospital known to those who have not used it
            - [DP4.1.1.1] advertise
            - [FR4.1.1.2] Make quality of Hospital known to those who have used it
            - [DP4.1.1.2] Keep hospital quality

    - [FR4.1.2] ability to divert patients to facilities that can accept them immediately
    - [DP4.1.2] ambulance diversion
  - [FR4.2] Meet target LOS (Throughput is maximized while maintaining clinical quality, satisfaction and safety)
  - [DP4.2] LOS time reductions (Efficient Processes that make proper use of resources and are unaffected by external problems)
    - [FR4.2.1] Reduce Process Delay
    - [DP4.2.1] Process designed for quickness
    - [FR4.2.2] Reduce Transportation delay
    - [DP4.2.2] Patient flow oriented layout
    - [FR4.2.3] Reduce systematic operational delays (A Balance between medical resources and medical demands is maintained)
    - [DP4.2.3] system design to avoid interruptions
    - [FR4.2.4] Reduce delays due to external entities
    - [DP4.2.4] Design to compensate for transfer problems and testing problems
  - [FR4.3] Manage Output
  - [DP4.3] Procedures for moving patients
    - [FR4.3.1] Provide for further treatment outside of ED quickly
    - [DP4.3.1] Admit to hospital
      - [FR4.3.1.1] Have clear procedures for when patient is to be moved
      - [DP4.3.1.1] Moving and Discharge criteria
      - [FR4.3.1.2] Have ability to move patients when they meet criteria
      - [DP4.3.1.2] Discharge procedures and space in Hospital
    - [FR4.3.2] Remove patients that will not be admitted to hospital as soon as possible
    - [DP4.3.2] ED discharge
      - [FR4.3.2.1] It is clear when a patient it to be discharged
      - [DP4.3.2.1] Clear discharge standards
      - [FR4.3.2.2] Patient is discharged to maximize output
      - [DP4.3.2.2] discharge as soon as possible

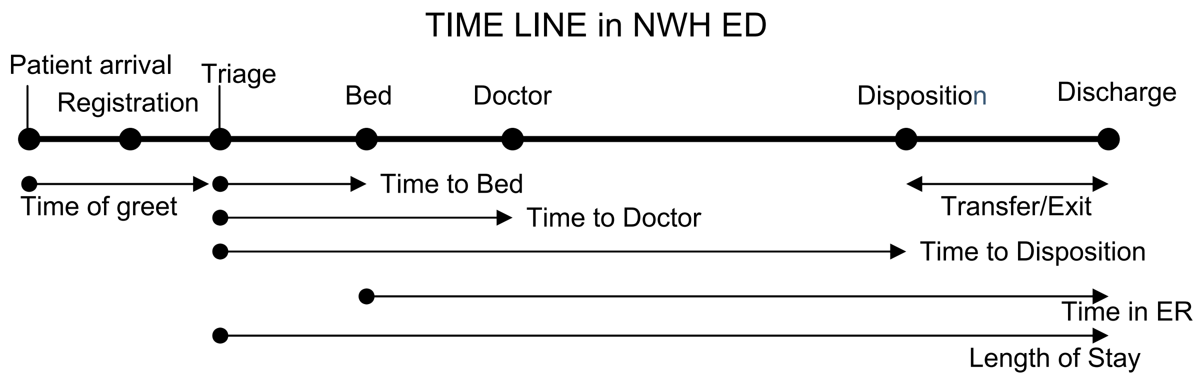
A.6 ED^3 FR5 - Growth

- [FR5] Ability to adopt new technologies and practices
- [DP5] Research and Development
  - [FR5.1] new technologies are incorporated
  - [DP5.1] Research and Development of Technologies
    - [FR5.1.1] awareness of new technologies is maintained
    - [DP5.1.1] Technology Research
    - [FR5.1.2] ability to procure new technologies is maintained
    - [DP5.1.2] Purchasing Plan and budget
    - [FR5.1.3] ability to train staff in new technologies
    - [DP5.1.3] staff education
    - [FR5.1.4] ability to implement new technologies
    - [DP5.1.4] change management competencies

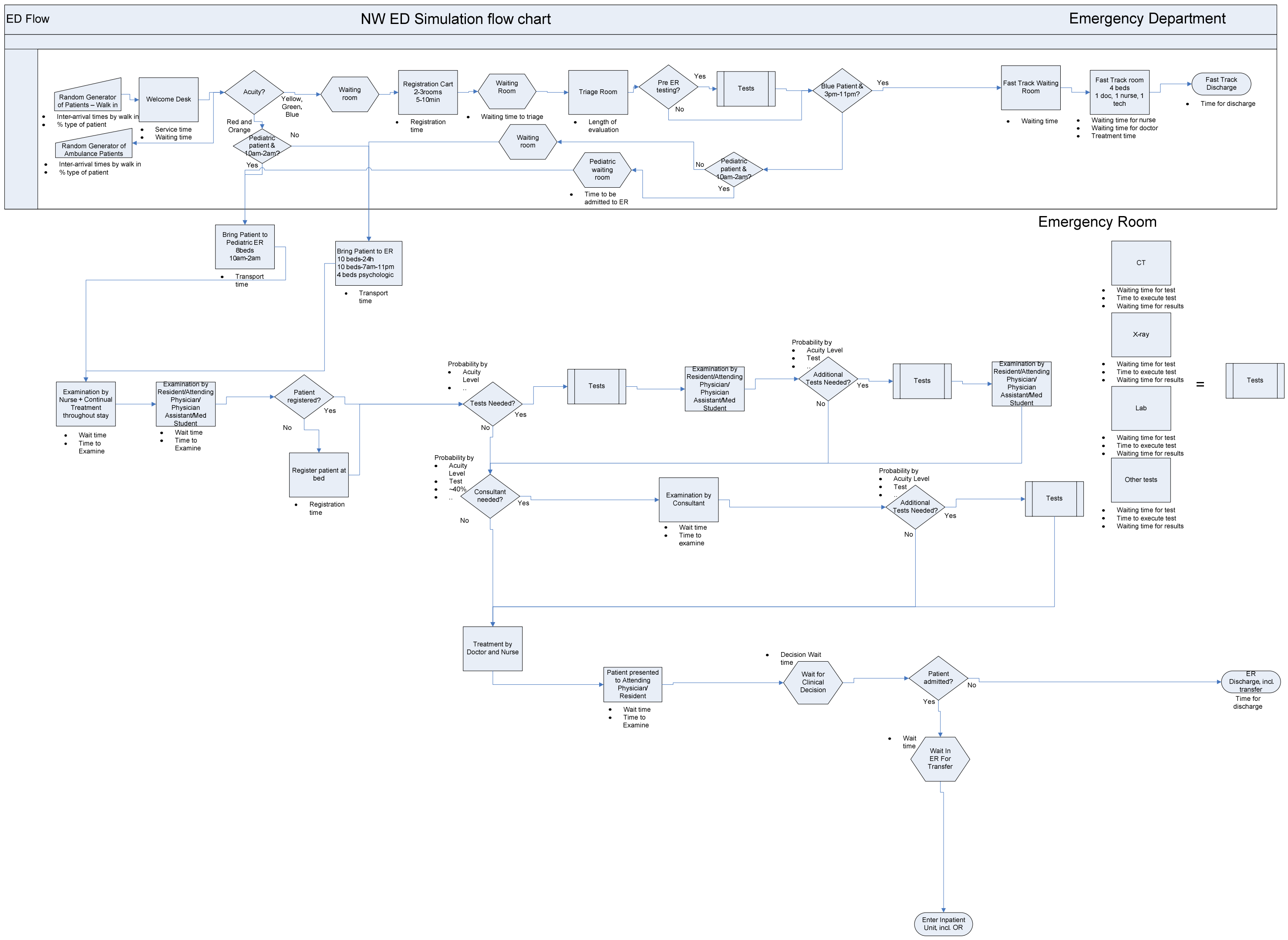
- [FR5.2] new practices are incorporated
- [DP5.2] Research and Development of Practices
    - [FR5.2.1] Awareness of new practices is maintained
    - [DP5.2.1] Practices Research
    - [FR5.2.2] management system that can require changes
    - [DP5.2.2] Management Hierarchy
    - [FR5.2.3] Ability to train staff in new practices
    - [DP5.2.3] staff education
    - [FR5.2.4] change management to oversee change
    - [DP5.2.4] change management competencies
- [FR5.3] Ability to learn from past mistakes
- [DP5.3] Error Report and Processing system
    - [FR5.3.1] ability to report mistakes
    - [DP5.3.1] anonymous reporting system
    - [FR5.3.2] ability to process mistakes
    - [DP5.3.2] experts who read and evaluate mistakes
    - [FR5.3.3] ability to create new practices from findings
    - [DP5.3.3] distribution of evaluation results

B. Discrete Event Simulation Model

B.1 Time Metrics Used to Describe Patient Flow



B.2 Flow Chart of ED Process



B.3 Percentages, Distribution Equations and coefficients for cumulative PI levels for each ESI

ESI 5 Treatment time = TRIA(4, 15.4, 118)

PI Level	Percentage of ESI 5 sent to FT
1 (0-30min)	9.38
1-2 (0-60min)	40.63
1-3 (0-90min)	59.38
1- 4 (0-120min)	81.25
1- 5 (0-150min)	93.75

ESI 4 Treatment time = 1 + GAMM(G1, G2)

PI Level	Percentage of ESI 4 sent to FT	G1	G2
1 (0-30min)	14.13	3.83	3.04
1-2 (0-60min)	41.40	8.24	2.58
1-3 (0-90min)	62.38	16.3	1.96
1- 4 (0-120min)	77.50	22.9	1.78
1-5 (0-150min)	84.43	27.1	1.68

ESI 3 Treatment Time = .999 + B1*Beta(B2,B3)

PI Level	Percentage of ESI 3 sent to FT	B1	B2	B3
1 (0-30min)	1.33	24.5	1.43	1.42
1-2 (0-60min)	6.85	57.5	2.1	2.59
1-3 (0-90min)	14.86	87.5	1.7	1.95
1- 4 (0-120min)	25.11	117	1.54	1.56
1- 5 (0-150min)	37.48	146	1.61	1.56

ESI 2 Treatment Time = 2 + B1*Beta(B2, B3)

PI Level	Percentage of ESI 5 sent to FT	B1	B2	B3
1 (0-30min)	.64	23.5	.158	.327
1-2 (0-60min)	4.33	49.5	1.06	1.16
1-3 (0-90min)	9.31	75.5	1.08	.954
1- 4 (0-120min)	19.26	115	1.66	1.48
1- 5 (0-150min)	32.58	147	2.04	1.75

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