2006

An AHP framework for balancing efficiency and equity in the United States liver transplantation system

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An AHP Framework for Balancing Efficiency and Equity in the United States Liver Transplantation System

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Industrial Engineering
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College of Engineering
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Date of Approval:
November 1, 2006

Keywords: Multi-Criteria Decision Analysis, Data Mining, Healthcare Policies, SAS, Medical Decision Making, Modeling

DEDICATION

To my wonderful parents, Veerachandran and Jayalakshmi

ACKNOWELDGEMENTS

I would like to thank my Father, Mother and Sister for their love and continued blessings throughout my coursework and research. I thank Dr. Nan Kong for his easy accessibility and tolerance. His expectations and dedication to work has been a great source of inspiration and encouragement which is reflected through out this research.

I would like to thank my committee members Dr. Jose Zayas-Castro and Dr. Kingsley Reeves, for their continued support and guidance. Finally, I would like to thank all my friends for their support and good wishes in my studies.

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AN AHP APPROACH FOR BALANCING EFFICIENCY AND EQUITY IN THE UNITED STATES LIVER TRANSPLANTATION SYSTEM: A PILOT STUDY

Vijayachandran M. Veerachandran

ABSTRACT

Liver transplantation and allocation has been a controversial issue in the United States for decades. One of the main concerns in the allocation system is the trade-off between the two main objectives, efficiency and equity. Unfortunately, it is difficult to reach consensus on how to develop allocation policies that aim at balancing efficiency and equity, among transplantation policy makers, administrators, transplant surgeons and transplant candidates.

Our research identifies and classifies the outcomes of liver allocation into two major categories, efficiency and equity, that are, often times, conflicting. Previous researchers did not consider how to balance outcomes in these two categories. Our research uses Analytic Hierarchy Process, a Multi-Criteria Decision Analysis methodology, to build a framework that quantifies the decision-making process and help decision makers to reach a valid consensus in terms of balancing these outcomes. Latest available patient registration and follow-up data are used in data analysis**.** Results from

This research addresses the deficiencies of the current liver transplantation policy and is intended to refine the policy that will result in a more balanced allocation system with respect to efficiency and equity. Our proposed methodology can be applied to incorporate further changes in policy selection and refinement.

CHAPTER 1

INTRODUCTION

1.1 Current Health-Care Scenario in the United States

Improved public health policy and improvements in medical care have increased the life expectancy of the average American from 49 years in 1900 to an all time high of 77.4 years in 2002 [1]. More amounts are spend for health-care awareness and improvement. The United States remains the leading nation in global healthcare spending: an average of $ 4,500 per person [2]. On a per capita basis, health spending in the U.S. is 50% higher than in the second-highest spending country, Switzerland, according to the Organization of Economic Co-operation and Development (OECD) figures [3]. In 2005 the U.S. healthcare industry grew as a more demanding population sought the best healthcare they could afford. The Center for Medicare and Medicaid Services (CMS) reports that health care expenditure in the United States is expected to continue growing to 16.2% of the Gross Domestic Product (GDP) in 2005, up from 16% in 2004 [4] [7]. By 2015 health care expenditure in the United States is projected to reach $4 trillion and contributes to 20% of the GDP [5]. This makes the health-service industry the largest in the U.S. The aforementioned data suggests that even a small improvement in health-care or associated services might have significant effect on the overall economy and life expectancy.

World Health Organization (WHO) statistics show that the U.S. ranks 37th out of 191 countries in performance metrics for overall levels of population health, system responsiveness, health inequalities or disparities among the population and distribution of the financial burden [6]. In 2005, the costs of health insurance premiums continued to rise in the U.S., rising costs are likely to affect the country's healthcare industry [7]. The U.S. Census Bureau stated that 46 million Americans now lack health insurance. Expenditure on health services more than doubled in 2005 from ten years earlier. Rising costs of a health insurance is a growing concern; more and more people are living without adequate health insurance, Nearly 46 million people in U.S. have no health insurance, which means these individuals will be deprived of proper treatment solutions in times of necessity [8].

The Business Communication Company (BCC) reports that more than half of the health care expenditure in the United States are for organ failures or tissue loss, an amount that exceeds $600 billion [9]. They also reported that over 215,000 people die in the U.S. every year from diseases that are treatable with transplantation. The National Foundation for Transplants reports the average cost for a kidney transplant ranges from $75,000 to $100,000, liver transplants from $250,000 to $275,000 and lung transplants from $200,000 to $250,000. The U.S. Organ transplantation was a $4.2 billion market in 2002 of which 76% is attributed to kidney and liver transplantation. The market is projected to grow at a rate of 5% to $5.4 billion by 2007 [9].

1.2 Organ Allocation in the U.S.

An organ transplant is the transplantation of a whole or partial organ from one body to another, for the purpose of replacing the recipient's damaged or failing organ with a functioning one from the donor. Organ donors can be living, or cadaveric. In the United States, there's a great shortage of donor organs: hearts, livers, lungs, kidneys, pancreases and small intestines. Even though there is an increase in the number of transplants and available livers for transplantation, there is wide disparity between the number of organs needed for transplantation and number of organs available. Over 92,000 Americans are currently waiting for an organ transplant at any given day, and this number is increasing and is expected to reach 100,000 by the end of 2010 [10]. In 2005, only about 28,000 organ transplants were performed. On average, 114 people are added to the nation's organ transplant waiting list each day -- one every 13 minutes. Nearly 6,500 people died in 2005 because no organs were available.

Lack of available donors in this country lead to the death of 3,886 kidney patients, 1,811 liver patients, 457 heart patients and 483 lung patients in 2004 while waiting for life-saving organ transplants. Almost 10 percent of the patients currently waiting for liver transplants are young people under 18 years of age. On November 30, 2001, 2,348 children under age 18 were registered on the organ transplant waiting list. Candidates for kidney transplants top the waiting list followed by liver candidates and lung candidates published by the United Network for Organ Sharing (UNOS),

Our research focuses on the study of liver transplantation. Liver transplantation remains the only treatment for end-stage liver disease (ESLD); however the number of patients who could benefit from a transplant far exceeds the number of available cadaveric donors. There is a wide disparity in the allocation of organs based on various characteristics for example patients with type O blood wait the longest for a liver transplant--an average of 1,243 days [13]. People with type AB wait the shortest time--an average of 210 days. Waiting time has clinically and statistically significant effect on the probability of graft failure outcomes following transplantation. For every fifty days of wait time on the list for a transplant the probability of graft failure at one year increases in between 1% and 2%.

1.2.1 United Network for Organ Sharing

The United Network for Organ Sharing (UNOS) manages the nation's organ transplant system and oversees a comprehensive database of clinical transplant information under a contract with the federal government. UNOS maintains and operates the computerized organ sharing system by matching donated organs to patients registered on the national organ transplant waiting list. UNOS seeks to increase organ donation through the education of the public to the dire need of organ transplants and the improvement of transplant success rates through outcomes-based research and policymaking [14]. The strength of the transplant database relies on the active reporting of 412 UNOS member institutions.

1.3 Liver Transplantation

Liver transplantation is necessary for the cure of most causes of acute or chronic liver disease. Liver transplantation is appropriate to any acute or chronic condition resulting in irreversible liver dysfunction, provided that the recipient does not have other circumstances that will preclude a successful transplant. Cirrhosis is the main reason for more than 80% of transplantations performed in adults, (hepatitis C and alcoholic liver disease are the two most common diagnoses). According to (UNOS), there are more than 17,000 patients on the national waiting list for a liver transplant. Yet, in 2002, only 5,329 liver transplantations were performed [14]. The large disparity between the number of available deceased donor organs and qualified recipients awaiting liver transplantation has created ongoing debate about selection criteria, the timing of transplantation, and attempts to expand the donor pool as a result of increasing mortality rates among listed patients.

1.3.1 Research Motivation

UNOS data shows that 10 percent of the waiting population dies before a liver is available [14]. Unfortunately liver transplantation ranks among the most expensive medical services and costs hundreds of thousands of dollars [16]. The existing system of liver allocation gives more preference to patients living near donor, (i.e. more emphasis is placed on geography than trying to ensure urgency). Only organs which are not suited within an Organ Procurement Organization (OPO) is given out for regional allocation and later if there is no match found in the region is offered nationally. There is very little rationale explaining the reason behind this.

The existing system takes into account of medical factors including waiting time and HLA level medical severity calculated using Model For End Stage Liver Disease (MELD) score and blood compatibility [21]. Efficiency is more and more emphasized in the existing policy and little effort is given to make the system equitable in terms of geography, race gender and others, As a result the system that fails to address the equity issues associated.

The risk of death among women, Asians, Hispanics and children are more than that of rest of the population due to a longer waiting time for transplant than foreign nationals and repeat transplant patients [17]. There exists a wide disparity in waiting times across different regional allocation of livers ranging from 31 days to 207 days [18] [20].

The number of patients registered for transplant doesn't match with the rapidly growing mortality rate associated with shortage of organs. Procured livers remain transplantable only for a limited period of time based in the Cold Ischemic Time (CIT) normally ranging from 18 – 24 hours [19]. Two most important issues associated with allocation delays and maximum utilization of this scarce life saving resource are 1) Quality of match and 2) increase in rejection rate. About 10 to 15% of patients die while waiting for transplantation. Due to the severe shortage of livers, an increase in the quality of the allocation procedure and policy is critical for ESLD patients.

1.3.2 National Organ Transplant Act

The responsibility of the Organ Procurement and Transplantation Network (OPTN), formed by the National Organ Transplant Act (NOTA) of 1984, ensures the national registry of organ transplants is established with an emphasis on the development of equitable and efficient organ allocation policies [22]. NOTA asserts that a proper system to allocate donated organs for transplantation among transplant centers and patients should be ranked according to established medical criteria. The Senate Labor and

Human Resources Committee amended NOTA with the following: an equitable system is necessary such that individuals throughout the country can have equal access to organ transplantation when appropriate and necessary [22]. The allocation of transplantable organs has been the subject of considerable debate throughout the transplant community during the last decade [23]. A debate which reached congress in 1998 remains unsettled since then.

The UNOS is responsible for managing the national organ donation and allocation system. The current allocation procedure was approved for implementation on February 28, 2002 [14]. In the last six years there has been four changes in policy [24]. These multiple changes highlight the challenge in forming a consensus on allocation policy.

1.3.3 Efficiency and Equity in Liver Allocation

The goal of a proper allocation policy is to identify a system which is equitable and efficient. In an equitable system, each individual on a transplant waiting list has an equal opportunity to receive a transplant subject to established medical and demographic criteria. No discrimination or privilege for one patient over another based on region, ethnicity etc. Efficiency implies the diminution of the wastage of donated livers available for transplantation. Equity in our research is measured in terms of the difference over efficiency outcomes.

1.4 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is capable of combining qualitative and quantitative criterions in decision making processes. The AHP model is successful in practice and has numerous and diverse applications. AHP’s capability of handling complex decision problems is well acknowledged. AHP can handle complex and poorly defined problems which rigorous mathematical models display difficulty in solving. AHP has the ability to handle mix qualitative and quantitative criteria within the same decision framework. It also helps create a consensus of scenarios or situations by converting qualitative decisions to quantitative data. AHP has the ability to handle both tangible and intangible attributes, define the structure of a scenario through its inherent hierarchical model and verify the consistency of end decisions

1.5 Research Contributions

This research aims to balance the trade-off between efficiency and equity in liver transplantation, an issue that is heavily debated. This framework can also be used for making similar policies addressing the efficiency and equity tradeoff. The AHP approach is used to quantify the decision making process and build logics with complex decision making criteria for policy selection. This research addresses the concerns regarding the need for a change in allocation policy, which needs to reduce or eliminate inequity in organ transplantation system.

The latest data from UNOS is used in our research. This research uses AHP methodology for organ allocation. Even though numerous application of AHP can be found in complex medical decision analysis process, as such none of the applications uses the capability of AHP in selection and evaluation of organ allocation policies. Our research aims to address the concerns in liver allocation policy by tying efficiency and equity together, which previous researchers held separate.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses the literature related to the research. In section 2.1 we will introduce Analytic Hierarchy Process (AHP), describe several applications, and summarize various solution techniques. In section 2.3 we will summarize previous studies that apply AHP to medical decision making problems. In section 2.4 will discuss previous decision making methodologies in the national liver allocation system. Finally, section 2.5 will provide analysis on the previous studies addressing efficiency and equity in liver allocation.

2.2 Analytic Hierarchy Process

AHP is a multi-criteria decision making tool that is flexible and used across wide variety of disciplines. It helps analyze both quantitative and qualitative aspects of a decision process. AHP was developed by Thomas L Saaty in 1970 [25]. An advantage of AHP over other multi-criteria decision making methods is that the AHP can incorporate tangible as well as intangible factors, especially when the subjective judgments of different individuals constitute an important part of the decision process. The method is widely used in varying areas such as politics, economics, sociology, and even in medicine because of the following advantages: 1) this method can handle both quantitative and qualitative data all at once; 2) this method uses the eigenvector and eigen-value property, which presents a computational advantage 3) a reduction in cognitive burden to decision makers when comparing with other similar methods and 4) previous works have already verified the advantages of this method with numerous case studies. AHP has broad application areas including planning, resource allocation, conflict resolution and optimization and selection of the best alternative [26]. This research uses the selection approach of AHP: selecting the best alternative from a set of given feasible alternatives. AHP utilizes a numeric scale to calibrate the measurement of quantitative as well as qualitative performances (Table 2.1), the scale ranges from one to nine with one corresponding to least favored and progressively moving up the scale to nine which corresponds to very strongly favored.

Table 2.1 The Fundamental Scales (Saaty and Vargas, 2000)

Numerical Score	Definition	Explanation
1	Equal Importance	Two activities equally contributes to the objective
2	Weak	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

2.2.1 Methodology

AHP aids in formulating a multi-attribute decision problem in the form of a decision tree, where each of the hierarchy level involves a variety of criteria. It can be from a simple single level hierarchy to a multiple level (n) hierarchy. AHP addresses the decision problem of choosing the best alternative by systematic and quantitative comparison of different criteria using pair-wise comparison techniques. Mathematically, it determine the weights of the comparison pairs C_i for i = 1 to *n*' where n is the number of criteria.

AHP exceeds the comparative judgment approach by relaxing the normality assumption of parameters. In this research, AHP is used in this research to develop and analyze trade off between conflicting outcomes in the course of structuring reciprocal pair-wise comparison matrices.

AHP starts by breaking down the problem hierarchically; each level of the hierarchy consists of a few manageable elements. These elements are further sorted to another set of sub-elements. This process continues until all specific elements of the problem are measured, which in turn represents the lowest level of the hierarchy. Structuring the problem hierarchically reduces the complex nature of the problem and helps identify the major components. It also helps us understand the problem in a better manner and sort the trivial and non trivial elements.

2.2.2 An Overview of AHP Applications

The AHP model has found numerous successful applications. An overview of AHP in various areas is presented in Vaidya and Kumar (2004). These applications for AHP include decision making in personal, social, manufacturing, politics, engineering, education, government and health care applications. The authors reviews several approaches used in AHP, selection, evaluation, priority, development, resource allocation, decision making, forecasting, medicine [26].

In a review of the 150 top-tier journals, the most popular applications of AHP falls either in the combination of engineering application and selection approach or social application and selection approach. AHP has been used in many cases as a stand-alone application however variations of AHP such as fuzzy AHP or a combination of AHP with tools like linear programming, artificial networks and fuzzy set theory makes it more versatile and expands the application areas. The application of AHP is also seen a increasing trend as more and more top tier research publications like the European Journal for Operations Research (EJOR) have special editions and annual symposium for AHP being held due its increased application areas.

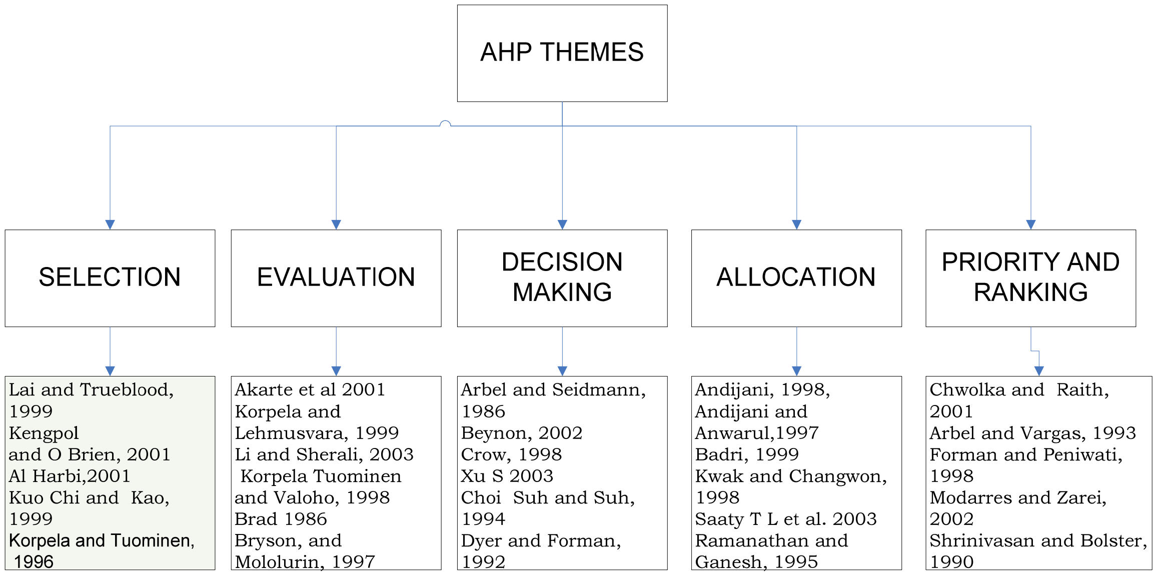

Figure 2.1 AHP Themes

2.3 Selection Theme

Forman and Gass (2001) mention several AHP applications in selecting best alternatives from a given set of multiple alternatives in a multi-criteria environment. The application areas include product selection, vendor selection and policy decision. Their paper talks about application of AHP in more than 50 research decision situations within the Xerox Corporation; such as portfolio management, engineering design selection, technology implementation, market segment prioritization and customer requirement prioritizing [27]. Sharp (1987) discusses the application of AHP in their selection of lowest cost haulers to handle the dispatches to reduce dispatch costs [29].

AHP has a significant role in group decision making, Dyer and Forman (2002) state the benefits of using AHP in group decision making through decomposition, comparative judgment and synthesis of priorities [30].

2.4 AHP in Health-Care

AHP has been a powerful tool to health care decision makers. Many common themes have been found in AHP aided decision making in the health care industry. This literature review will mainly discuss the application of AHP in clinical and medical decision evaluation. The problems mostly use the selection and decision making approach of AHP [26]. Application of resource allocation and prioritization themes can be found in a) medical staff decision making b) identifying alternative technologies to purchase, c) assisting patients in their decision making process. AHP is not only capable of analyzing economic and technical factors in the healthcare industry but also social and human factors [31[32] [33]. Hariharan et. al (2005) presents an application of AHP for measuring and comparing the global performance in quality of intensive care units [34].

Different approaches have been taken in health care decision making problems using AHP, as demonstrated in the following two examples. Wu, Lin and Chen (2006) apply AHP in optimal selection of locations for Taiwanese hospitals [35]. The model addresses the burgeoning health care quality consciousness among Taiwanese residents and improves scope of medical services considering a competitive advantage. Rosetti et al (2001) address decision problem for hospital deliver systems that addresses economic and technical performance as well as social human and environmental factors. The model enables a better understanding of delivery and transportation requirements in medium and large size hospitals [36].

2.5 AHP in Medical Decision Making

Min et. al (1997) propose a model which helps medical clinics improve service strategies in the competitive health care industry. Their research uses AHP for the comparative evaluation of quality benchmarking in health care service improvement [37]. A recent development in technology and bioethics enables an increased participation from patients in their own health care decision making, resulting in a shared decision making model Singpurwalla et al (1999) [39].

Liberatore et. al, (2003) uses AHP to model a shared decision making among patients and physicians for addressing the growing concern of prostate cancer in men. The model also successfully captures the decision-counseling protocol for cancer screening. The adaptability of AHP in modeling complex problems is emphasized to fit the research. The paper describes the methodology in three steps of which the first is identifying the alternatives available and personal criteria for evaluation. Secondly determining how the alternatives achieve the personal criteria based on analysis thirdly to determine the priority of the steps and finally deciding among alternatives. The study emphasizes the lack of training needed for patients who are involved in decision making and the addresses the necessity of more application of AHP to personal decision making [39]. Applications of AHP in medical decision making and medical decision support can be found [40 [41] [42].

Cook, Staschak and Green (1990) work on the equitable allocation of livers for orthotropic transplantation they consider the major factors to logistics, tissue compatibility, waiting time, financial and medical status. They rate the patients in terms of main categories based on their rank in subcategories using pair-wise comparisons [33].

They state that the system lacks formal evaluation and is based on the intuition of individuals involved. While equity is heavily emphasized, efficiency of the transplantation is poorly addressed. Equitable provision and healthcare financing is one of the National Health Service's (NHS) growing concerns since its inception (Sassi et al 2001). Awareness of widening health equities since the publication of Black report has raised equity to a high rank among policy makers.

CHAPTER 3

PROBLEM STATEMENT AND METHODOLOGY

3.1 Introduction

Allocating available livers to necessary patients involves a lot of discretion. Choosing an optimal liver allocation policy among a set of alternatives is a challenge given the subjective nature of this problem. The decision maker may not be able to make consistent decisions addressing the efficiency and equity in selecting policy. Decisions involved in selecting the best policy must consider various outcomes of liver transplantation including efficiency, equity and trade-offs between them [45]. This makes the problem a Multi-Attribute Decision Making problem (MADM). AHP is a MADM methodology which helps quantify the decision making process and gives decision makers the ability to reach a valid consensus in decision making rather than depending totally on their intuition [25].

3.2 Current Liver Allocation System

This section provides an overview of the existing liver allocation system. Knowledge of the existing system will help in understanding the difficulty faced by decision makers in allocating available livers to ESLD patients. UNOS operates the national system for organ transplantation. It is responsible for managing and administering the proper allocation of available organs for transplantation. The current liver allocation system was implemented in February 28, 2002 [20]. The policy has been changed four times in the last six years [21]. Numerous changes in such a small duration shows that there is a need for improvement in the liver allocation policy.

3.2.1 United Network for Organ Sharing

UNOS is responsible for every organ transplant performed in the United States. UNOS supervises the organ donation and procurement via non-profit agencies called Organ Procurement Organizations (OPO). OPOs provide organ recovery services, manage the clinical care of the donors, enter donor information into the UNOS computer database to find a match and coordinate the organ recovery process to hospitals located within designated geographical area in the U.S. OPO's also promote organ donation in their communities by sponsoring workshops and participating in community health fairs and events [14].

The national UNOS membership is divided into 11 geographic regions, each consisting of several OPOs. This regional configuration was developed to facilitate organ allocation and to offer individuals the opportunity to identify concerns regarding procurement, allocation, and transplantation of organs that are unique to their region.

The patients are divided in to two categories PELD and MELD based on the age. PELD score is for patients under 18 years of age. In our research we are focused on the adult liver allocation procedure. UNOS maintains a patient waiting list that is used to determine the transplant candidates among the patients. When a liver becomes available, the following factors are considered for its allocation: medical urgency of the patient, patients OPO, patient region, patient score from clinical and medical urgency, and patient waiting time (Figure 3.1).

UNOS provides a framework of principles for making policy decisions about organ allocation. Currently the existing systems follow a “sickest first” approach. Patients with severe medical urgency will be offered the liver first [47].

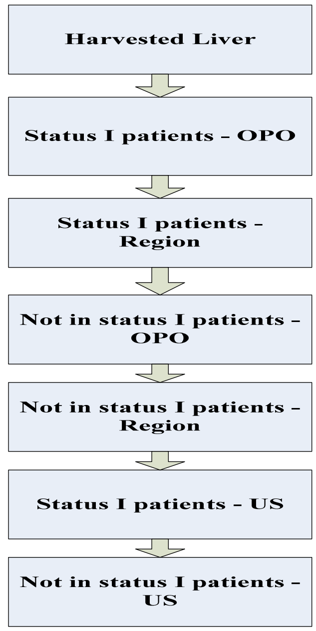

Figure 3.1 Schematic Representation of Current Liver Allocation System

Figure 3.1 explains about the current liver allocation procedure. Every liver available for transplant is first offered to those Status 1 patients located within the harvesting OPO based in descending order of MELD score. If there are no suitable Status 1 matches within the harvesting OPO, the liver is then offered to Status 1 patients within the harvesting region. If a match still has not been found, the liver is offered to all non-Status 1 patients in the harvesting OPO in descending order of MELD score. The search range is again broadened to the harvesting region if no suitable match has been found within the harvesting OPO. If no suitable match exists in the harvesting region, then the liver is offered nationally to Status 1 patients followed by all other patients in descending order of MELD score [14].

3.3 Liver Transplantation Issues

In the existing liver transplantation policy, more emphasis is given in the geography of patient than balancing the equity issues associated with the model. A harvested liver is first distributed according to medical condition and then by the proximity towards the transplant OPO. This results in wide inconsistency as a patient's chance of living or dead is based on where they live than their medical urgency [20]. The condition becomes worse when current policy allow people to list in more than one geographical region, known as multiple listing. Many patients who are able to list in more than one region stand a higher chance of obtaining a liver than people listed in only one region [21].

Any organ allocation policy should satisfy at least the following three performance goals: 1) identify and establish standardized criteria for measuring proper medical scores for eligibility of transplant patients before adding to the waiting list, 2) facilitate a fair comparison of patients across the waiting list. Geographical preference of the patients should be widely reduced and more emphasis should be give to the equity aspect [50]. A change in the increased emphasis on efficiency should be pushed by regulations to encourage a move to a more equitable system.

There is less rationale in providing a liver to a severe End Stage Liver Disease (ESLD) patient irrespective of the survival rate [20]. Two specific and somewhat conflicting goals should be considered for decision making in transplantation: efficiency of the transplantation and equity in transplantation [22]. Which one should be given more emphasis, fairness surely gives higher preference to equity, but utilization emphasizes on higher efficiency. We shall balance the efficiency and equity of these conflicting outcomes and reach a more desirable decision making policy.

3.4 Analytic Hierarchy Process

The AHP method by Saaty is based on two important theoretical principles: the fundamental scale for ratio comparison, and the eigenvector and eigen value property [25]. Saaty utilizes a fundamental scale ranging from one to nine. The scale has its origin on the Weber-Fechner's sensation (response) equation "Law of stimulus of measurable magnitude" (i.e. $M = a\log s + b, a \neq 0$) where M denotes the sensation and s the stimulus) (Fechner, 1966) [52] [53]. When making pair-wise comparisons, nearest integer approximation from the fundamental scales of one to nine is being used. This scale has been validated for effectiveness in many applications by numerous individuals through the theoretical justification of what scale one must use in the comparison of homogeneous elements (Saaty and Vargas, 2000) [54]. The upper limit of nine is adopted following Miller (1956)'s "Magical number theory" [55]. Alternatives are compared based on this fundamental scales in a pair-wise comparison fashion; then a decision matrix is composed [55].

3.5 Illustrative Example

We are using an example to explain the AHP methodology. There is an age old adage which says apples cannot be compared with oranges. Our objective is to choose the best fruit from a set of alternatives, including apple, orange and grapes. These can have many criterions in common: color, quality, appearance, seediness, etc. We may prefer an orange for color criteria but for appearance criteria an apple and for quality criteria grapes. Strength of our preference for these characteristics may vary. Even though we may be indifferent to some attributes there will be strong preference for some other attributes which may vary across circumstances.

The challenge is to identify a set of alternatives which strongly fulfills the goal which satisfies entire set of objectives. The decision making is concerned with weighing alternatives through pair-wise comparison.

3.5.1 Decomposition and Development of Hierarchy Structure

The AHP methodology suggests the development of a hierarchical structure. The formulation of a decision hierarchy is a critical step in AHP because it helps to effectively frame a problem and simplify the analysis process. It also helps to decompose the problem into inter-related decision element goals, attributes and alternatives. In our specific example the hierarchy structure consists of a three-level hierarchy consisting of a final objective goal, level of attributes through which these alternatives are being evaluated including color, quality, appearance and seediness and final level of alternatives, apple orange or grape to chose from (Figure 3.2).

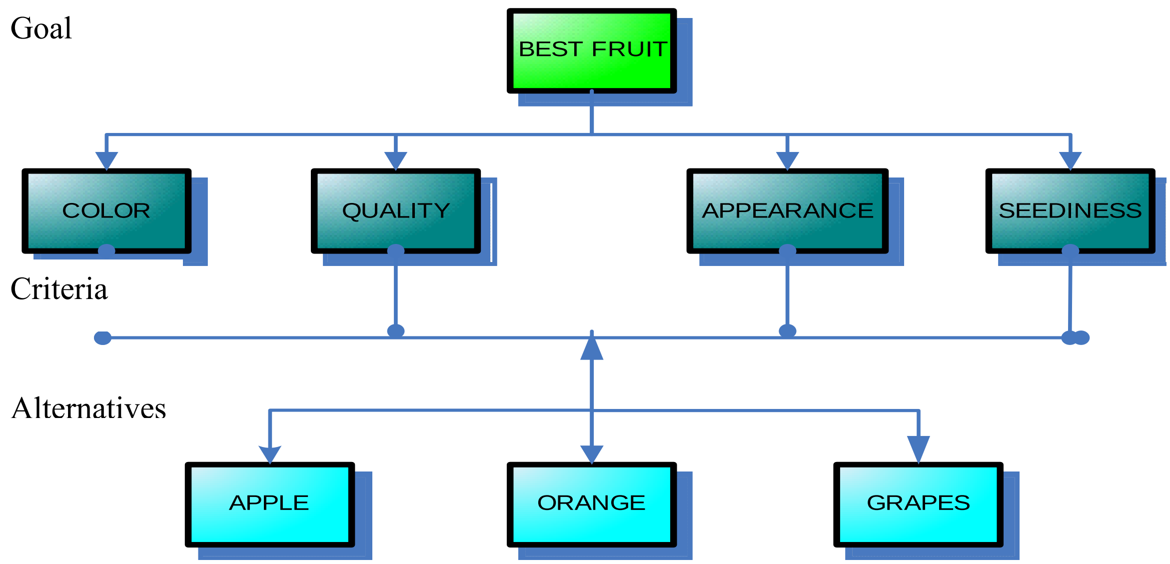

Figure 3.2 Evolution of Hierarchy Model for Fruit Selection

3.5.2 Evaluation of Hierarchy

The second step in an AHP process is the evaluation of the hierarchy.

1) Identify the preference weights (judgments) by pair-wise comparison of the decision elements.

2) Synthesize the preference weights to determine the most preferred alternative.

Let us consider the elements from C_1 , to C_n of some level in hierarchy. The weights of influence W_1, to W_n are found on some element in the next level. We will determine the pair-wise comparison matrix a_{ij} (i, j = 1, 2, n) which indicates the strength of C_i when compared with C_j. The matrix of these numbers a_{ij} is denoted A, or

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} & a_{1n} \\ 1/a_{12} & 1 & a_{23} & a_{2n} \\ 1/a_{13} & 1/a_{23} & 1 & a_{3n} \\ 1/a_{1n} & 1/a_{2n} & 1/a_{3n} & 1 \end{bmatrix} \quad (3.1)$$

The matrix can be also be denoted as $a_{ij} = 1/ a_{ji}$,, that is the matrix A is reciprocal. If at any level of hierarchy the attribute of C_i is of equal relative importance as C_j, then $a_{ij} = 1$, $a_{ji} = 1$; In particular $a_{ii} = 1$ for all i. If our judgment is perfect in all comparisons then $a_{ik} = a_{ij} * a_{jk}$ for all i,j,k, and we can call matrix A as a consistent matrix. In a consistent matrix the comparisons are based on exact measurements and; If the weights W_1, to W_n are already known. Then

$$a_{ij} = \frac{w_i}{w_j} \text{ (for i, j = 1, 2, …, n).} \quad (3.2)$$

thus

$$a_{ij} * a_{jk} = \frac{w_i}{w_j} * \frac{w_j}{w_k} = \frac{w_i}{w_k} = a_{ik} \quad (3.3)$$

This leads to

$$a_{ji} = \frac{W_j}{W_i} = \frac{1}{w_i / w_j} = \frac{1}{aij} \quad (3.4)$$

Considering the matrix equation

$$A.x = y \quad (3.5)$$

Where $x = (x_1 , \ldots\ldots. x_n)$ and $y = (y_1 , \ldots\ldots. y_n)$

$$\sum_{j=1}^{n} a_{ij} xi = y_i \text{ , (for i = 1, 2, …, n).} \quad (3.6)$$

This gives us

$$a_{ij} * \frac{w_j}{w_i} = 1, \text{(for i, j = 1, 2, …,n).}$$

Consequently

$$\sum_{j=1}^{n} a_{ij}\, wj = n wi \text{ (for i = 1, 2, …, n).}$$

Which is equivalent to

$$Aw = n\, w \tag{3.7}$$

where A is a consistent matrix. In general, small deviation in a_{ij} may lead to large deviations both in Eigen value λ_{max} and in W_i (for i = 1,2, to n). It necessitates the need for stable solutions which satisfies the condition. The reciprocal matrix satisfies the conditions and gives a more stable solution. When considering the reciprocal of the matrix A which is represented as A', from the pair-wise comparisons, the solution can be represented as

$$A'w' = n\, w' \tag{3.8}$$

Several approximation methods are available to identify the weights of the comparison vector of which, the most recommended method geometric approximation is utilized in this research. This method multiplies all the n elements in the pair-wise comparison matrix and the resulting weights of corresponding alternatives normal the results obtained by taking the nth root for matrix of n alternatives.

From our example consider the priority vector matrix

$$A' = \begin{bmatrix} 1 & 3 & 5 & 7 \\ 1/3 & 1 & 5 & 9 \\ 1/5 & 1/5 & 1 & 4 \\ 1/7 & 1/9 & 1/4 & 1 \end{bmatrix}$$

The multiplication of each row results in (105, 45/3, 4/25, and 1/252) respectively. Each value is raised to the power 1/n. In this example n = 4. The result is represented by priority vector p

$$P = \begin{bmatrix} 105^{(1/4)} \\ 45/3^{(1/4)} \\ 4/25^{(1/4)} \\ 1/252^{(1/4)} \end{bmatrix} = \begin{bmatrix} 3.201 \\ 1.968 \\ 0.632 \\ 0.251 \end{bmatrix}$$

These values are normalized using a linear normalization method. The sum of the all elements of column vector P is calculated, each element is then divided by that sum of elements. In our example, the sum of elements is found to be around 6.052. After normalization, the vector of weights is given by **w**.

$$\mathbf{w} = \begin{bmatrix} 3.201/6.052 \\ 1.968/6.052 \\ 0.632/6.052 \\ 0.251/6.052 \end{bmatrix} = \begin{bmatrix} 0.5289 \\ 0.3251 \\ 0.1044 \\ 0.0414 \end{bmatrix}$$

3.5.3 Consistency Index and Consistency Ratio

Consistency of the decision is a big issue to be addressed in any decision making methodology. The matrix A (a_{ij}) is said to be consistent only if the principal eigen value λ_{max} is equal to or close to the order of the matrix (n). The sum of the eigen values of a matrix is equal to its trace which is also equal to n.

The human involvement of AHP makes it difficult for any one to give the precise values of the pair-wise comparison ratio $\frac{w_i}{w_j}$, rather only an estimate. Therefore, Saaty replaces the equation Aw = nw with Aw = λ_{max} w. where λ_{max} is the largest or principal eigen value of matrix A. Saaty defines the difference between λ_{max} and n as a Consistency Index (CI).

CI is calculated by $CI = \frac{\lambda_{max} - n}{n - 1}$ (3.9)

The consistency index of randomly generated reciprocal matrix for the ratio scale 1 to 9, with reciprocals forced is called as Random Index (RI). At Oak Ridge National Laboratory, Saaty generated an average random index (RI) for matrices of order 1-15 using a sample size of 100. RI increases as the order of the matrix increases and is shown in the following table as the sample size was only 100 and statistical fluctuation of indexes from one order to the other (Table 3.2).

Table 3.1 Average Random Index (Oakridge National Laboratory)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The ratio of C.I to average R.I for matrix of the same order is defined as Consistency Ratio (C.R).

C.R = C.I / R.I (3.10)

Lower the consistency ratio will increase the consistency of the decision. Saaty recommends using matrices of consistency ratios less than 0.1. If the consistency ratio is greater than 0.1 such a matrix should be eliminated to calculate the weight so that the decision made is more rational. Thus AHP methods use a combination of C.R and powerful pair-wise comparison to resolve irrational humanistic responses.

Ideally, $a_{ij} = \frac{w_i}{w_j}$ (for i, j = 1, 2, …, n). We use judgments which are quantified, and all the allowances must be integrated. Deviations in the ratio a_{ij} and the number n, now denoted by λ_{max}, leads to λ_{max}

$$w_i = \frac{1}{\lambda_{max}} \sum_{j=1}^{n} a_{ij} w_j \qquad i = 1, 2, \ldots, n \tag{3.11}$$

A small deviation in a_{ij} can lead to a very large deviation in final weights. The consistency in decision should be maintained throughout for accurate measurement of the selection criteria.

3.6 Synthesis of Priorities

Once we have obtained weights of criteria, the next step is to prioritize the alternatives based on the criteria. For each criterion the alternatives are prioritized based on the decision matrix and priorities are obtained.

Pair wise comparison of criterion color is shown as follows

$$A' = \begin{bmatrix} 1 & 3 & 1/3 \\ 1/3 & 1 & 1/9 \\ 3 & 9 & 1 \end{bmatrix} \quad W' = \begin{bmatrix} .23076 \\ .0796 \\ .6923 \end{bmatrix}$$

The matrix and the weights based on one of the criterion color as shown in the above equation. The weight is obtained via the method previously mentioned. Similarly we can obtain the weights for other criteria including quality appearance and seediness (Table 3.3).

Table 3.2 Weights Among Alternatives With Respect to Criteria

Evaluation	Color	Quality	Appearance	Seediness
Weights	0.164798	0.185184	0.437111	0.212907
Apple	0.230769	0.142857	0.177276	0.0704176
Orange	0.076923	0.714286	0.0852256	0.751405
Grapes	0.692308	0.142857	0.737498	0.178178

3.7 Overall Priority for Final Selection

Finally, the priority weights of each alternative can be calculated by weights per alternative multiplied by weights of the corresponding criterion. The highest score of the decision matrix implies the best choice of fruit. Synthesizing the priorities will give us the weights of the criteria and the priorities of the alternatives based on each individual criterion. Now we have to obtain the overall priority ranks which will help us in making the decision.

For obtaining the overall ranking of alternatives we multiply the corresponding alternatives with the weights of the criterion weights.

$$\text{Ranking} = \text{Priorities} \times \text{Weights of Criteria} \qquad (3.12)$$

The weight of alternative apple based on the criterion color is obtained by

$$\text{Weight of apple based on color} = 0.230769 \times 0.16472 = 0.038030$$

Similarly weights of other alternatives are also obtained by sum product

Table 3.3 Sum Product of Matrix

SUM PRODUCT	Color	Quality	Appearance	Seediness	Results
Apple	0.03803	0.0264	0.0774892	0.014992	0.15696
Orange	0.012676	0.1322	0.037253	0.159979	0.34218
Grapes	0.11409	0.0264	0.3223684	0.037935	0.50084

3.8 Results

According to the decision matrix final scores, grapes are the most preferred due to its high priority weight, Orange is the next recommended alternative. Through the illustration of this AHP model, it is found that the fruit selection problem can be solved in a structural and simple manner without involving much complexity. The sensitivity of each fruit with respect to the attributes and main criteria also can be obtained. The final priority weights of each fruit can be seen in Figure 3.3. The step by step computations and comparison matrices of all the attributes are shown. The important results are also shown in Figure 3.3.

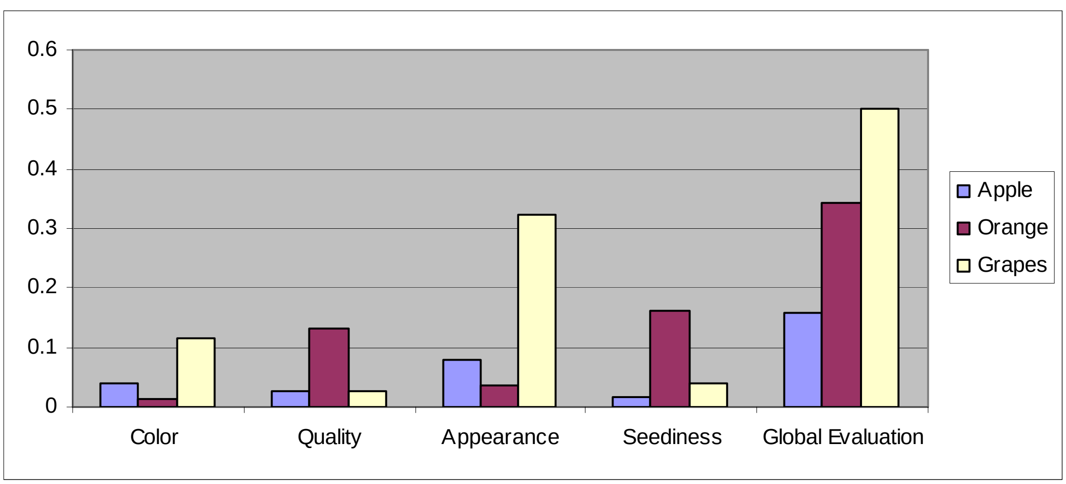

Figure 3.3 Final Priority Weights Alternatives by Criterion

The final priority weights of different criteria shows that the appearance of the fruit carries the highest priority and it is followed by seediness, quality and color, respectively. The factors that contribute most in fruit selection are appearance and seediness.

CHAPTER 4

MODEL DEVELOPMENT

4.1 Introduction

This chapter discusses decision making involved in finding a trade-off between efficiency and equity outcomes which were modeled in a Multi-Criteria Decision Analysis framework using Analytic Hierarchy Process. Additionally, important decision criteria related to efficiency and equity involved in deciding the best policy are detailed. The criteria discussed include average MELD score, waiting time, racial and geographic equity which require considerable amounts of attention. We attempt to generalize the model for all organ transplantation including liver, kidney, and tissues etc.

4.2 AHP Framework

Balancing efficiency and equity in U.S. liver transplantation can be modeled as a multi-criterion decision problem which includes both qualitative and quantitative factors. Reaching a consensus in selecting a policy is more complex when there are conflicting attributes involved. AHP based methodology will be discussed to tackle the different necessary but conflicting criteria. In our research criterion like efficiency and equity including the sub criterions involved in the selection of alternative policy based on existing liver transplantation scenario. In this research AHP is used to identify a consensus in which how much a system should be balanced in terms of efficiency and equity outcomes. This research concentrates on a widely divided category of organ transplant's outcomes; i.e. efficiency and equity. The aim of the National Organ Transplant Act (NOTA) is to develop a policy which is efficient and equitable. Categorized outcomes are as shown in (Table 4.1). The table comprises some of the major outcomes which, we believe, affect an efficient and equitable distribution of harvested organs.

Table 4.1 Classification of Efficiency and Equity Outcomes

Efficiency	Equity
Average Cold Ischemic Time (Hours)	Race
No. of Previous Transplants	Ethnicity Category
Age in Years at Time Of Listing	Gender
Recipient Length of Stay Post Transplant	State of Residency at Registration
Recipient Died (1=Dead,0=Alive)	
Cold Ischemic Time (Hours)	
No. of Days on Liver Waiting List	
Average MELD Score	
Age In Years At Time Of Listing	
Recipient Length of Stay From Transplant to Discharge	
Recipient Days Between Previous And Current Transplant	
Allocation Type: Local/Regional/National/Foreign	

We categorize the measurable outcomes into two main subsets: Efficiency and Equity. In the preliminary step for finding the optimal policy we break down the decision problem into further criteria. These criteria will aid in building the hierarchy model, thus facilitating the easy understanding of the problem and easing application of AHP methodology.

4.3 Selection Criteria for Liver Transplantation

Most decision makers cannot simultaneously handle more than 7 to 9 factors when making a decision involving alternatives that have multiple attributes. It is necessary to break down complex problems into more manageable sub problems which help decision making. There is a large number of contributing but conflicting factors simultaneously affecting the process of reaching a decision. An orderly sequence of steps should be required whereby a complex problem, is broken down into to sub-problems reducing complexity and produces an easy analysis.

Liver transplantation has four level of hierarchy. The following sections discuss the different decision criteria, attributes and the decision alternatives. The objective is to select a best liver allocation policy which balances efficiency and equity for the U.S. liver transplantation system. Application of common criteria to all alternative policies makes pair-wise comparisons possible.

The criteria which are considered are:

1. Efficiency

2. Equity

4.4 Liver Transplantation Outcomes

Liver transplantation outcomes are divided into efficiency and equity outcomes. Our research focuses on efficiency and equity outcomes of the existing model for liver allocation. Efficiency refers to the utilitarian view towards the systems and intends to make the existing system efficiency oriented. In the equity oriented approach, the egalitarian view argues for the equity of the system in all terms including gender, race, geography, etc. It is a challenge to develop a decision to process that is capable of balancing efficiency and equity amongst large number of alternatives.

4.4.1 Efficiency Outcomes

The efficiency criterion is an important criterion in assessing the policy because it can determine the effectiveness of the system in terms of utilization of scarce resources. A good policy cannot be possible without maximum utilization of the available transplantable livers. Considering a high rejection of more than 45%, maximum utilization of transplantable livers should have a major influence [57].

While most of the medical factors including medical urgency, waiting time and age have been taken in consideration some issues are not properly addressed; some of the major factors (attributes) affecting this criterion can be stated as follows

4.4.1.1 Average MELD/ PELD Score

Efficiency of the system is attributed to the scoring model for calculating the severity of disease. The MELD score reflects the patient's risk of dying while waiting for a liver transplant based on clinical tests. . The MELD and PELD scores range from 6 to 40 and are based on objective and verifiable medical data. The MELD score is used for adults, while the PELD score is used for patients who are less than 12 years of age. The higher the MELD or PELD score, the greater the risk of dying from liver disease

The MELD score calculation uses:

- Serum Creatinine (mg/dl)*
- Bilirubin (mg/dl)
- INR

MELD Formula

MELD Score = 0.957 x Log_e (creatinine mg/dL)
+ 0.378 x Log_e (bilirubin mg/dL)
+ 1.120 x Log_e (INR)
+ 0.643
Multiply the score by 10 and round to the nearest whole number.

The PELD score calculation uses:

- Albumin (g/dl)
- Bilirubin (mg/dl)
- INR
- Growth failure (based on gender, height and weight)
- Age at listing

PELD Formula

PELD Score = 0.480 x Log_e (bilirubin mg/dL)
+ 1.857 x Log_e (INR) - 0.687 x Log_e (albumin g/dL)
+ 0.436 if patient is less than 1 year old
+0.667 if the patient has growth failure
Multiply the score by 10 and round to the nearest whole number.

The likelihood of a critically ill person receiving a liver is higher than that of patient who has a higher recovery chance. In the current scoring system, the median wait time for re-transplant candidates is less than that of new transplant candidates. A factorization of the score can be done based on transplant history. One of the primary efficacy outcome is survival rate of patients after transplantation. Additionally, the quality adjusted life years is another major outcome. Length of time in the waiting list and quality of the liver obtained also attribute a lot towards the efficiency issues. Average MELD score, length of hospitalization, rejection rate are secondary factors for deciding the efficiency of a transplant.

4.4.1.2 Average Waiting Time

The length of time spent on the waiting list is another major attribute for the efficiency of the system. For a more efficient system it is necessary that the average wait time be reduced. This is a major factor in the measuring MELD scores. The wait time determines the priority when there is a tie amongst patients of similar MELD or PELD scores.

4.4.1.3 Acceptance Rate

Higher acceptance rate is directly related to the efficiency of the policy. It is necessary for any alternative policy to have a very low rejection rate. There is a wide gap between the available livers for transplantation and number of patients in the waiting list. Liver transplantation is very expensive and costs hundreds of thousands of dollars. A higher acceptance rate can substantiate the high cost involved with liver transplantation and associated costlier post transplant medication.

4.4.2 Equity Outcomes

Equity of the liver allocation system should be viewed as equal as efficiency. The measurement of equity contributes toward the fairness of a policy. Numerous criteria which we can measure equity; are blood group, race, insurance, health conditions, ethnicity, transplant OPO etc, as such important for any policy to be fair so that no policy should be biased on things beyond their control. Our research considers, what we think, a major contribution toward the equitable allocation via as geography, race and gender. We consider the measurements as we view their inclusion as a means to create a more equitable policy. Equity outcomes in this research are measured in terms of the difference in scores of specific efficiency outcomes over patient. For example The difference in the MELD score across Hispanics Asians, Whites and African Americans.

4.4.2.1 Geographical Equity

Geographical equity is one of the major contributions toward the fairness of liver allocation policies. The regional variability in wait time has prompted vigorous debate on organ allocation policy. Certain parts of the nation failed to benefit from the regional bias of current liver allocation policy. It is necessary for an ideal policy to reduce the regional variability in allocation of livers.

4.4.2.2 Gender Equity

There is a wide disparity in the post transplant survival rate and acceptability of organs based on the male and female. Any ideal policy should be able to recognize and reduce this disparity to its bare minimum while maintaining an acceptable efficiency level.

4.4.2.3 Racial Equity

Another major equity criterion measured is race. No policy should disadvantage anyone for belonging to a certain race. Even though the current system does not explicitly account for racial consideration, it is observed that there is a high racial disparity in the number of transplants as well as the waiting time for people belonging to a particular race. Any system should be fair in such a way that the difference among the race in terms of efficiency attributes should be minimized or negligible.

For all the major equity criteria and corresponding sub criteria, pair wise comparisons are done in terms of the difference in the efficiency attributes. For example if we consider the geographical equity criterion we will measure the difference in average wait time across the different regions based on the national average. Similarly pair wise comparison will be done for other criteria to obtain a quantitative justification in determining priorities among the criteria.

4.5 Hierarchy Model

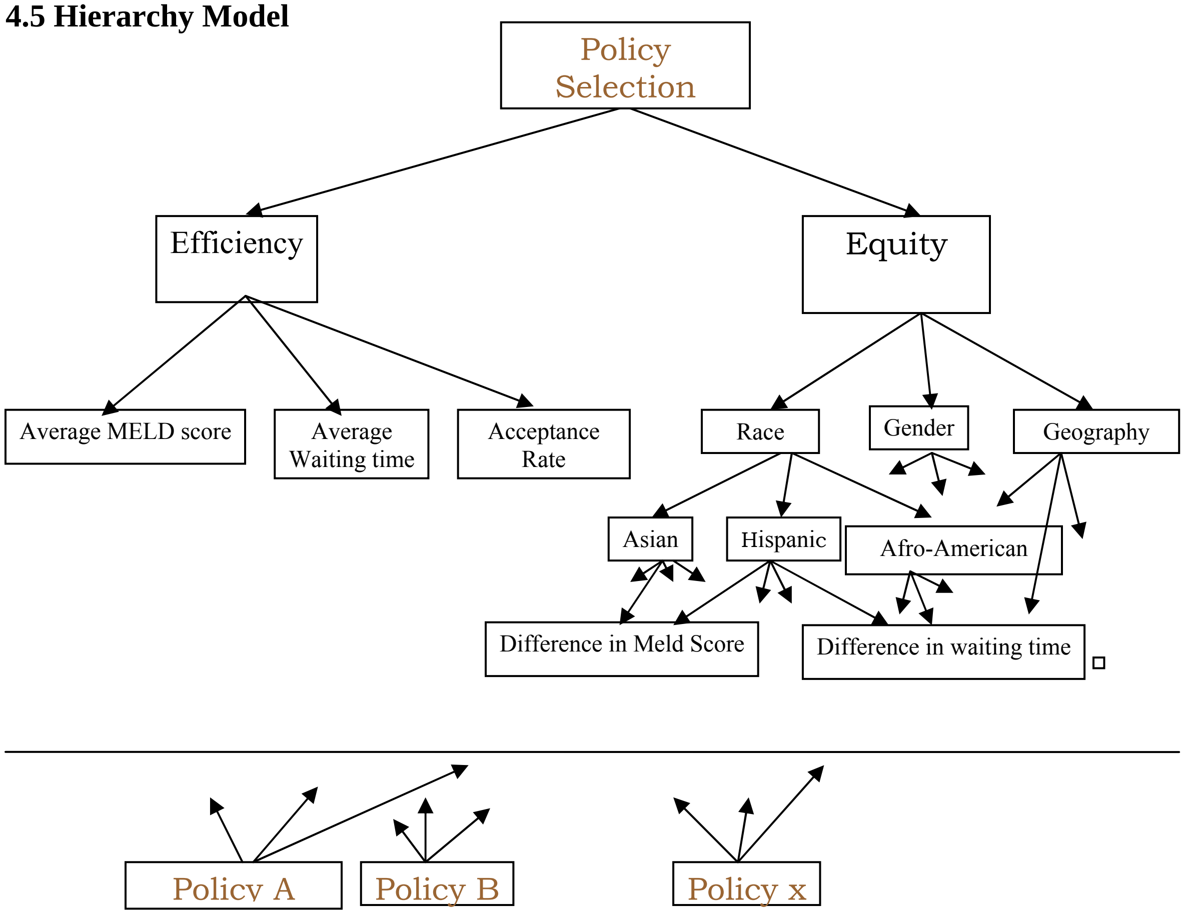

Figure 4.1 Evolution of AHP Model for Balancing Efficiency and Equity

4.6 Discussion of Methodology and Application

The problem discussed is the U.S. Liver transplantation and allocation policy; searching for the best policy for balancing efficiency and equity. The research takes into account the majority of possible criteria which can affect the decision maker. A detailed discussion on every criterion, sub criterions, attributes and alternative policy has been presented. Two critical criteria have been identified. The methodology has been used further to select the numerous attributes (or sub-criteria) with for evaluating among alternative policies.

The following steps have been considered to form the hierarchy:

(1) Define the issues considering the U.S. liver transplantation.

(2) Identify the overall objective of policy selection.

(3) Identify the criteria and attributes that must be satisfied to fulfill the overall objectives.

(4) Identify decision alternatives or outcomes.

(5) Structure the hierarchy placing the objective at first level, criteria at second level, attributes at third level, and decision alternatives at fourth level.

CHAPTER 5

DATA ANALYSIS AND RESULTS

5.1 Introduction

In this chapter we will discuss about the sources of data, data extraction methods, variables for analysis, simulation models, and data analysis software.

5.2 UNOS Data

The UNOS operates the national system for organ transplantation. As mandated by policy, all transplanting institutions must report certain information for each transplant performed. The UNOS liver committee selects the relevant set of variables to be report, which are collected on standardized forms made available by UNOS. UNOS makes the information publicly available in electronic format.

Two sets of latest data requested from UNOS.

1. Patient registration data
2. Patient follow-up data

5.2.1 Patient Registration Data

This data is provided as a SAS cport file. A cport file is a sequential file containing one or more data sets or catalogs in SAS format. "Transport format" is a format understood by all versions of SAS in all systems. The data contains waiting list / transplant files. UNOS Standard Transplant Analysis and Research (STAR) files for liver registrations and transplants were obtained. The transplant STAR file from UNOS contains information on all waiting list registrations and transplants of livers that have been listed or performed in the U.S. and reported to the OPTN since October 1, 1987. The data includes both deceased and living-donor transplants. There is one record per waiting list registration/transplant event. Each record includes the most recent follow-up information (including patient and graft survival) reported to the OPTN as of June 2006. The patient information dataset consists of 142,873 records and 418 variables. These variables are further classified into post transplant clinical information, pre-transplant clinical Information, candidate information, donor information, waiting list data, etc.

5.2.2 Patient Follow-Up Data

The follow-up STAR file contains one record for each pre-transplant measurement. There are multiple records per transplant for most cases. For instance, if a patient was transplanted in January 1998, the graft has not failed, and the patient has not been reported lost to follow-up database, we have many follow-up records with the same transplant identification number i.e. transplant id. Follow up records for 6 month, 1 year, 2 year, 3 year, 4 year, 5 year, and 6 year etc can be obtained for each patient. The variable for linking the follow-up data to the transplant STAR file is TRR_ID. The number of record of patient ranges from one record to more than hundred records per patient based on number of visits or tests conducted. The patient follow up dataset consists of 675,279 records and 20 variables. Most of the variables are from the waiting list category.

5.3 Statistical Analysis System (SAS)

The SAS system is an integrated system of software products provided by the SAS Institute that enables programmers to perform data analysis. In this research latest version of SAS 9.1.3 (released on April 2006) licensed to University of South Florida is used.

5.4 Data Patterns and Simulation Model

The main objectives of data analysis are to understand the system and to obtain the inputs for a discrete-event liver transplantation simulation model. The simulation model is intended to replicate the real life system. Patient's cumulative distribution can be obtained by using their MELD scores as input from the patient registration dataset. This data was extracted from corresponding SAS dataset by avoiding the duplicates and based on the year of focus. Appendix A presents the sas program to determine the variables for extraction and the procedure for extracting the data. The different outcome categories and configurations based the data input comprise the input for the simulation model that will be described later in the chapter.

5.5 Extraction Procedures and SAS Data Sets

The SAS software package was used to extract the data from the database. SAS file Extract1.sas is presented in Appendix A and was used as the master program that aids in identifying the variables needed from each data file. These variables will be described in more detail in the next section. Figure 5.1 illustrates the complete procedure used in extracting all data in tables.

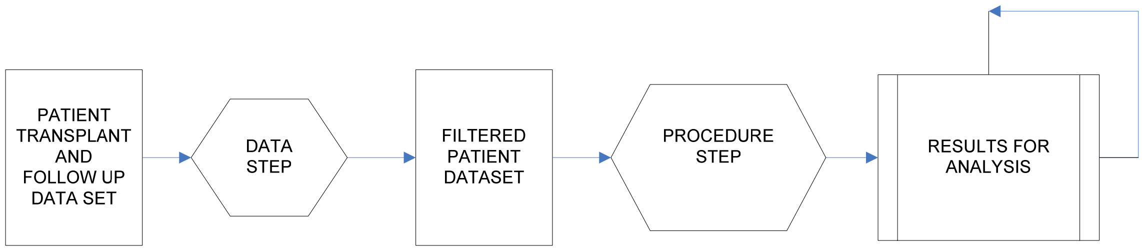

Figure 5.1 SAS Data Extraction Flow Chart

The hexagonal blocks represents the processing steps, the square blocks represent the data sets and tabulated results. The purpose of the PROC (Procedural) step is to perform operations on data obtained from data step. Finally, the results of the analysis were processed using Excel.

The analyzed data serve as input to the simulation model. The simulation model is a clinically based, discrete event simulation model of ESLD in the United States. The model is used for policy evaluation. It used input clinical data obtained from the analysis. The model is used to generate outcomes. The outcomes are evaluated based on expert's opinion to obtain the weights of the evaluation criteria. Impacts on changes in policy to various outcomes can be measured in this model.

5.5.1 Organ Procurement Organizations (OPO)

Each OPO considered is classified either as a transplant OPO or a donor OPO depending on its functionality. For this research it is necessary to fix the number of transplant and donor OPOs. We obtained all the distinct OPOs in use at any given time starting from its inception. We are able to identify 87 donor OPOs and 57 transplant OPOs. These are the variables that we obtained from the dataset:

CTR_OPO --Transplant OPO.

OPO_CTR -- Donor OPO.

The dataset obtained is displayed in appendix B.

5.5.2 Regions and Transplant OPOs

The entire UNOS is divided into 11 regions for geographical allocation and administrative purposes. Each OPO belongs to certain region based on the proximity. Each region consists of multiple OPOs. It is necessary to find the regional allocation of OPOs for all the identified transplant and donor OPOs. This information will be used to evaluate regional equity. We classified the two major categories of OPOs to their respectable regions.

Variables used from the dataset

Region – Region which an OPO belongs to.

CTR_OPO --Transplant OPO.

OPO_CTR -- Donor OPO.

We are able to classify all OPOs into different regions based on the analysis and the result will be obtained from appendix C.

5.5.3 Discrete Distributions

This analysis provides the patient arrival rate for the simulation model. We fixed the number of transplant OPOs as 57 for the research purpose. For 142,873 patient's information which we obtained the patients transplant OPOs, a discrete distribution based on these OPOs was obtained. There is wide disparity in the number of transplants. Patients from New York and California nearly attributes to the 15% of all the transplants.

5.5.4 Cold Ischemic Time

Cold Ischemic time is a major factor that determines the quality of transplant livers. Preservation methods are available for storing livers without much deterioration in quality for at least 12 hours [58]. We conducted this analysis by finding the distance between the Donor and Transplant OPOs and the cold ischemic time of patients for that transplant. We sorted the entire database based on the distance between the transplant center and the mean cold ischemic time is extracted. Few transplants have taken place when the donor and transplant OPOs are more than 2500 miles. For close analysis the OPOs are further subdivided to the distance of 100 miles for distance less than 2500 miles. For distance less than 500 miles we further divided the distance into sub categories of 50 miles. A normal distribution was fitted with 95% confidence interval.

5.6 Data Variables and Hierarchy

A hierarchy model helps decompose the problem in several stages. The aim of the model is to obtain a policy among the alternative policy recommendations. How do we test the alternative policies? Alternative policies can be tested for efficiency and equity based on certain outcomes of the policy that are obtained from the simulation model.

The model generates waiting list times and survival rates, graft failure, and re-transplant rates under the current UNOS liver allocation strategy, which emphasizes the severity of disease and incorporates the MELD risk score. A set of outcomes for various policies being obtained from the simulation model.

The outcomes of the simulation model were reviewed by experts. These Experts include transplant policy makers, physicians, and or focus groups among patients. They suggest the importance of the outcomes. Values from the outcomes obtained from the survey can be used to calculate the weights. This will help prioritize the impact of allocation policy and the contribution of each policy towards efficiency and equity of the model.

5.7 Merge – Registration and Follow-Up Data

The main objective of this part of the analysis is to create a library to store the extracted data and create a working data set from each of the two distinct data sets. As mentioned above, the database includes two datasets files, the patient registration data and patient follow-up dataset, necessary variables from each file were chosen from the data sets and finally the files were merged by patient id number (wl_id in the database). Merging was done to obtain the patient file information where the necessary variables for analysis were found in two different datasets

The Extract1.sas was updated in every analysis. Specific data sets are extracted from the database based on certain parameters for example based on year, MELD score, PELD score etc. In order to extract a specific set of data in a tabular format, smaller SAS programs were created. Sample sas program (Subextract.sas) is presented in Appendix A. This program extracts the patient id, initial and final MELD scores, Dates of visit to transplant center etc from the follow up file.

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

6.1 Concluding Remarks

In this research we studied efficiency and equity, two major conflicting factors of the United States liver transplantation. This research aims to find a policy which balances efficiency and equity of current liver transplantation. The problem was modeled using Analytic Hierarchy Process.

This research classifies the outcomes of liver transplantation into two major criteria: efficiency and equity. The majority of the attributes contributing towards these criteria have been identified. Some of the attributes which contribute to efficiency are average MELD score, length of wait time, and patient rankings. Major attributes that contributed toward equity included geographical location, race and gender. The AHP approach helps quantify the decision making process to build logics into a complex decision evaluation process that involves policy selection. The proposed model is capable of obtaining the weights of these defined attributes with the goal of establishing the major criteria regarding efficiency and equity.

Results from our data analysis that used the latest UNOS data, serve as inputs for a simulation model. The simulation model is capable of evaluating different strategies for liver allocation; the resulting outcomes can be quantified for decision making purposed using the proposed model. The AHP methodology helps decision makers reach a consensus in a quantifiable method whereas previous methods heavily rely on intuition.

This research studies the deficiencies of the current liver transplantation policy and proposes alternative strategies that may help policy makers search for a better policy to balance efficiency and equity. Measurement of alternative policies can be done using the simulation model. The proposed model is flexible enough to accept future changes in the U.S. liver transplantation policy.

6.2 Future Extensions

Some of the extensions that can be made for this research are:

1. Selection of proposed policy can be done through AHP model.
2. Different perspectives (policy makers or patients) towards the allocation policies can be studied.
3. The optimality criterion can be included for future research.

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APPENDICES

Appendix A: Statistical Analytics Systems Program

```
/* Initializing the CPORT File and Data Extraction*/
libname lib "C:\Documents and Settings\vveerach\Desktop\SAS\newdata";
/* where you want the new data to go */
Filename tranfile 'C:\Documents and
Settings\vveerach\Desktop\newdata\LIVER_PUBLIC_USE_WLHIST_CPORT_FILE';
/* Where the transport file is stored now */

 proc cimport library=lib infile=tranfile;
run;

options fmtsearch = (newlib)  /* this will enable SAS to find the
formats in the catalog*/
libname lib "C:\Documents and Settings\vveerach\Desktop\SAS\newdata";

/*Extracting the value coloumns from the table*/
proc sql;
create table anew as select x.WL_ID,
            x.ASCITES_DATE,
            x.MELD_PELD_LAB_SCORE
from lib.Liver_wlhistory_data x;
run;

proc sql;
create table meldnew as select distinct WL_ID,Date,
meld_peld_lab_score, MELD_OR_PELD
from Anew
where meld_peld_lab_score and date is not missing;
group by wl_id;
run;


proc sort data=Anew;
  by WL_ID ASCITES_DATE;
run;

data meld_prog_date;
    set Anew;
    by wl_id;
    retain dt -1;
    if first.wl_id then do;
          days=0;
          dt =ASCITES_DATE ;
    end;
    else do;
         days = ASCITES_DATE - dt;
    end;
    drop dt;
        where wl_id and ascites_date is not missing and meld_or_peld =
'MELD';
```

Appendix A: (Continued)

```
drop meld_or_peld;
run;
proc print; run;


proc sort data=meld_prog_date out=meld_prog_date_norepli nodupkey;
by wl_id ascites_date;
run;

data MELD_Progression;
set d3;
drop ASCITES_DATE;
drop meld_or_peld;
run;



proc freq data=d3;
by wl_id;
run;


/*New Programs*/

data newtab;
    set Anew;
    by wl_id;
    do;
         days = ASCITES_DATE - MDY(01,01,1999);
    end;
    drop dt;
        where wl_id and ascites_date is not missing;
run;
proc print; run;

data newtab_final;
set newtab;
where days >=0 and _SCORE>=6;
run;

proc sort data=newtab_final out=result2 nodupkey;
by wl_id ascites_date;
run;

proc contents data=a.a;
run;


proc sql;
```

Appendix A: (Continued)

```
create table result3 as select WL_ID, Days, meld_peld_lab_score
from result2;
run;


/*Remove Missing*/

proc sql;
create table newtable as select distinct WL_ID,ASCITES_DATE,
MELD_PELD_LAB_SCORE
from Anew
where ASCITES_DATE and MELD_PELD_LAB_SCORE is not missing;
run;

data newtable1;
set newtable;
where ascites_date le mdy(1,1,2003);
run;


/*No Missing*/
proc sort data=newtable1 out=Followup_2003;
by descending ascites_date;
run;

proc sort data=followup_2003 nodupkey;
by wl_id;
run;


proc sql;
create table new as select distinct WL_ID,ASCITES_DATE,
MELD_PELD_LAB_SCORE
from Anew
where ASCITES_DATE and MELD_PELD_LAB_SCORE is not missing;
run;

data new1;
set new;
where ascites_date le mdy(1,1,2002);
run;


/*No Missing*/
proc sort data=new1 out=Followup_2002;
by descending ascites_date;
run;

proc sort data=followup_2002 nodupkey;
```

Appendix A: (Continued)

```
by wl_id;
run;

/*Coverting days from January 2002 to number of days*/
data newtab;
    set followup_2002;
    do;
         days = ASCITES_DATE - MDY(01,01,2002);
    end;
run;

proc sql;
create table finalfinal as select WL_ID, Days, meld_peld_lab_score
from newtab;
run;
/*Start New 2002 2003 2004 2005 */
data new1;
set new;
where ascites_date le mdy(1,1,2003);
run;


/*No Missing*/
proc sort data=new1 out=Followup_2003;
by descending ascites_date;
run;

proc sort data=followup_2003 nodupkey;
by wl_id;
run;


data newtab2003;
    set followup_2003;
    do;
         days = ASCITES_DATE - MDY(01,01,2002);
    end;
run;

proc sql;
create table final_followup_2003 as select WL_ID, Days,
meld_peld_lab_score
from newtab2003;
run;


data new1;
set new;
where ascites_date le mdy(1,1,2004);
run;
```

Appendix A: (Continued)

```
/*Sorting and Ascending by removing the duplicates Missing*/
proc sort data=new1 out=Followup_2004;
by descending ascites_date;
run;

proc sort data=followup_2004 nodupkey;
by wl_id;
run;


data newtab2004;
    set followup_2004;
    do;
         days = ASCITES_DATE - MDY(01,01,2002);
    end;
run;

proc sql;
create table final_followup_2004 as select WL_ID, Days,
meld_peld_lab_score
from newtab2004;
run;



data new1;
set new;
where ascites_date le mdy(1,1,2005);
run;


/*No Missing*/
proc sort data=new1 out=Followup_2005;
by descending ascites_date;
run;

proc sort data=followup_2005 nodupkey;
by wl_id;
run;


data newtab2005;
    set followup_2005;
    do;
         days = ASCITES_DATE - MDY(01,01,2002);
    end;
run;
```

Appendix A: (Continued)

```
proc sql;
create table final_followup_2005 as select WL_ID, Days,
meld_peld_lab_score
from newtab2005;
run;


/*Meld And PELD SCORE*/
data End2002;
set Final_followup_2002;
where MELD_PELD_LAB_SCORE>=6;
run;


data End2003;
set Final_followup_2003;
where MELD_PELD_LAB_SCORE>=6;
run;
data End2004;
set Final_followup_2004;
where MELD_PELD_LAB_SCORE>=6;
run;

data End2005;
set Final_followup_2005;
where MELD_PELD_LAB_SCORE>=6;
run;


/*CHANGE IN MONDAY*/
Data FINAL_FOLLOW_UP;
    set followup_all;
    by wl_id;
    do;
         days = ASCITES_DATE - MDY(01,01,2002);
    end;
    drop dt;
        where wl_id and ascites_date is not missing;
        retain ascites_date;
run;

proc sql;
create table final_all_all as select WL_ID, Days, meld_peld_lab_score
from final_follow_up;
run;

data final_all;
set final_all_all;
where days >0;
run;
```

Appendix A: (Continued)

```
proc sort data=final_all nodupkey;
by wl_id days;
run;


PROC SORT DATA=a.Final_2003;
BY wl_id;
PROC SORT DATA=a.Final_followup_2003;
BY wl_id;
DATA widedata;
MERGE a.final_2003 a.Final_followup_2003;
BY wl_id;
RUN;

/*Merging the data sets from Patient Registration and patient follow up
database*/
data three;
      merge a.Final_2003(in=fromdadx)
a.Final_followup_2003(in=fromfamx);
      by wl_id;

     fromdad = fromdadx;
    fromfam = fromfamx;
             if fromdad=1 and fromfam=1;
     run;
PROC FREQ DATA=three;
TABLES fromdad*fromfam;
where fromdad=1 and fromfam=1;
RUN;
```

Appendix B: Donor and Transplant OPO

Table B.1 Transplant OPO vs. Donor OPO

No	Transplant OPO	Donor OPO
1	ALOB-OP1	ALOB-OP1
2	AROR-OP1 11	AROR-OP1
3	AZOB-OP1	AZOB-OP1
4	CADN-OP1	CADN-OP1
5	CAGS-OP1	CAGS-OP1
6	CAOP-OP1	CAOP-OP1
7	CARO-OP1	CARO-OP1
8	CASD-IO1	CASD-IO1
9	CORS-OP1	CORS-OP1
10	CTOP-OP1	CTOP-OP1
11	DCTC-OP1	DCTC-OP1
12	FLMP-OP1	FLFH-IO1
13	FLUF-IO1	FLMP-OP1
14	FLWC-OP1	FLSW-OP1
15	GALL-OP1	FLUF-IO1
16	HIOP-OP1	FLWC-OP1
17	IAOP-OP1	GALL-OP1
18	ILIP-OP1	GAMC-IO1
19	INOP-OP1	HIOP-OP1
20	KYDA-OP1	IAIV-IO1
21	LAOP-OP1	IAOP-OP1
22	MAOB-OP1	ILCL-OP1
23	MDPC-OP1	ILCR-OP1
24	MIOP-OP1	ILIP-OP1
25	MNOP-OP1	INOP-OP1
26	MOMA-OP1	KYDA-OP1
27	MSOP-OP1	LAOC-OP1
28	MWOB-OP1	LAOP-OP1
29	NCCM-IO1	LAOS-OP1
30	NCNC-OP1	LASU-IO1
31	NEOR-OP1	MAOB-OP1
32	NJTO-OP1	MDPC-OP1
33	NMOP-OP1	MIOP-OP1
34	NYFL-IO1	MNOP-OP1
35	NYRT-OP1	MNRC-OP1
36	OHLB-OP1	MOMA-OP1
37	OHLC-OP1 12	MSOP-OP1
38	OHLP-OP1	MWOB-OP1
39	OHOV-OP1	NCBG-IO1
40	OKOP-OP1	NCCM-IO1
41	ORUO-IO1	NCNC-OP1
42	PADV-OP1	NEOR-OP1
43	PATF-OP1	NJTO-OP1
44	SCOP-OP1	NMOP-OP1

Appendix B: Donor and Transplant OPO

Table B.1 (Continued)

No	Transplant OPO	Donor OPO
45	TNDS-OP1	NVLV-OP1
46	TNMS-OP1	NYAP-OP1
47	TXGC-OP1	NYFL-IO1
48	TXSA-OP1	NYRC-OP1
49	TXSB-OP1	NYRT-OP1
50	UTOP-OP1	NYSB-IO1
52	VAOP-OP1	OHLB-OP1
53	VATB-OP1	OHLC-OP1
54	WALC-OP1	OHLP-OP1
55	WANW-OP1	OHMV-IO1
56	WISE-IO1	OHOV-OP1
57	WIUW-IO1	OKHM-IO1
58		OKOP-OP1
59		ORUO-IO1
60		PADV-OP1
61		PATF-OP1
62		PRLL-OP1
63		SCOP-OP1
64		TNDS-OP1
65		TNET-OP1
66		TNMS-OP1
67		TXAD-IO1
68		TXBC-IO1
69		TXFW-IO1
70		TXGC-OP1
71		TXLG-IO1
72		TXSA-OP1
73		TXSB-OP1
74		UNKN-OP1
75		UTOP-OP1
76		VAFH-IO1
77		VAOP-OP1
78		VATB-OP1
79		WALC-OP1
80		WANW-OP1
81		WASH-IO1
82		WISE-IO1
83		WISL-IO1
84		WIUW-IO1
85		WVMS-OP1
86		ZCAN-FOP
87		ZFOR-FOP

Appendix C: Cold Ischemic Time Vs Distance

Table C.1 Analysis for 0 - 5000 in range of 100 miles

Analysis for 0 - 5000 in range of 100 miles						
Distance - Miles	Mean CIT	LCL	UCL	SD	Var	Range
0 - 100	8.0399	7.9931	8.087	4.5655	20.8438	50
100 - 200	9.2977	9.2149	9.38	4.398	19.3424	150
200 - 300	9.8012	9.6868	9.916	4.5425	20.6343	250
300 - 400	10.0359	9.8478	10.22	5.2455	27.5153	350
400 - 500	10.1749	9.9574	10.39	4.867	23.6877	450
500 - 600	10.3177	10.066	10.57	5.2922	28.0074	550
600 - 700	10.8373	10.542	11.13	4.8056	23.0938	650
700 - 800	11.1372	10.816	11.46	4.8368	23.3946	750
800 - 900	10.8209	10.495	11.15	4.9589	24.5907	850
900 - 1000	11.9619	11.467	12.46	5.2669	27.7402	950
1000 - 1100	10.8845	10.425	11.35	4.7745	22.7959	1050
1100 - 1200	11.6717	11.118	12.23	4.4073	19.4243	1150
1200 - 1300	11.5631	10.887	12.24	5.8062	33.712	1250
1300 - 1400	11.6803	10.831	12.53	5.2437	27.4964	1350
1400 - 1500	12.3073	11.746	12.87	3.9215	15.3782	1450
1500 - 1600	13.0943	12.239	13.95	5.6182	31.5642	1550
1600 - 1700	13.3862	12.533	14.24	5.2145	27.191	1650
1700 - 1800	13.096	12.307	13.89	3.8089	14.5077	1750
1800 - 1900	15.0422	14.351	15.73	5.2262	27.3132	1850
1900 - 2000	15.5607	14.483	16.63	5.563	30.947	1950
2000 - 2100	14.1942	13.371	15.02	5.2225	27.2745	2050
2100 - 2200	13.9505	12.719	15.18	6.2371	38.9014	2150
2200 - 2300	13.2455	12.156	14.34	4.5704	20.8886	2250
2300- 2400	14.3079	11.91	16.71	4.9756	24.7566	2350
2400 - 2500	8.775	2.6667	14.88	3.8387	14.7356	2450

Only 14 readings for distance between the transplant centers greater than 2500.

Analysis for 0 - 500 miles in range of 50 miles						
Distance - Miles	Mean	LCL	UCL	SD	Var	Range
0 - 50	7.7897	7.7351	7.844	4.6128	21.2779	25
50 - 100	8.7992	8.7119	8.887	4.3447	18.8764	75
100 - 150	9.247	9.1358	9.358	4.3716	19.1109	125
150 - 200	9.4103	9.293	9.528	4.4444	19.7527	175
200 - 250	9.6498	9.5067	9.793	4.434	19.6604	225
250 - 300	9.96	9.7771	10.14	4.6427	21.5547	275
300 - 350	9.7486	9.498	9.999	5.2697	27.7697	325
350 - 400	10.3845	10.107	10.66	5.2251	27.3017	375
400 - 450	10.262	9.9587	10.57	4.9757	24.7576	425
450 - 500	10.0516	9.7451	10.36	4.7187	22.2661	475

Appendix C: (Continued)

Table C.2 ANOVA Table for Patients Arrivals

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.8874623
R Square	0.7875894
Adjusted R Square	0.761038
Standard Error	0.3801294
Observations	10

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4.2862407	4.28624	29.6629	0.000611
Residual	8	1.1559871	0.1445		
Total	9	5.442227			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	8.39059	0.24132	34.769	5.1E-10	7.83410	8.9470	7.83410	8.9470
X Variable 1	0.00455	0.00083	5.44637	0.00061	0.00262	0.0064	0.00262	0.0064

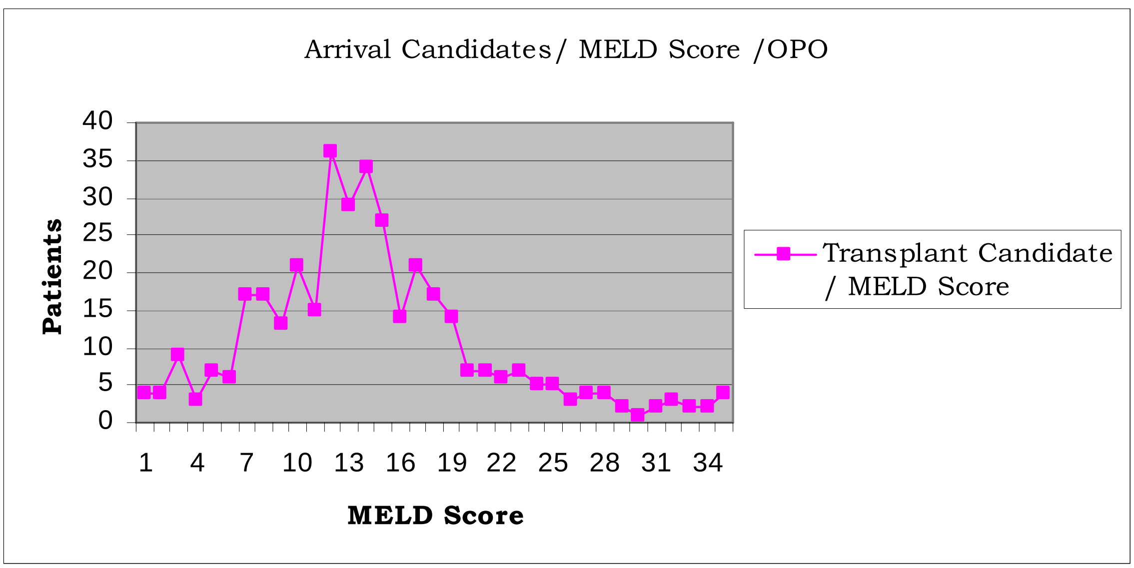

Figure C.1 Arrival of MELD Patients / OPO

Appendix C: (Continued)

Table C.3 ANOVA for Distance vs. CIT

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.7255							
R Square	0.5263							
Adjusted R Square	0.5057							
Standard Error	1.3935							
Observations	25							
ANOVA								
	Df	SS	MS	F	Significance F			
Regression	1	49.627	49.627	25.56	4.066E-05			
Residual	23	44.662	1.9418					
Total	24	94.289						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	9.3651	0.5577	16.791	2E-14	8.2113027	10.51882	8.211303	10.51882
X Variable 1	0.002	0.0004	5.0554	4E-05	0.0011543	0.002753	0.001154	0.002753

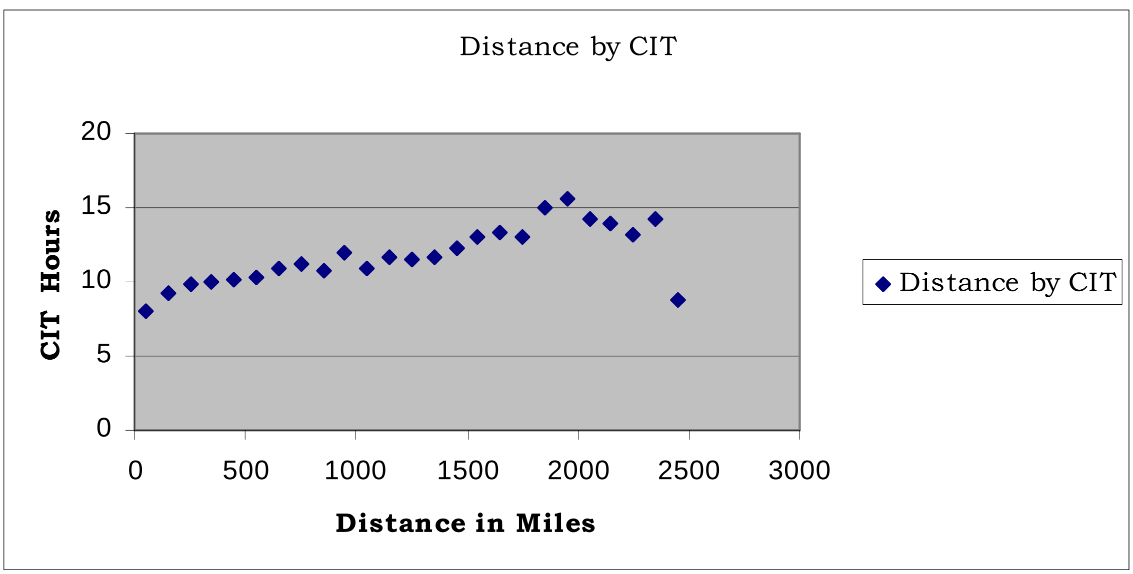

Figure C.2 Distance vs. CIT 100 miles