DEVELOPMENT OF A FRAMEWORK AND ANALYSIS SYSTEM TO SUPPORT INTERVENTION IN NEWBORN HEALTHCARE

by

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ABSTRACT

DEVELOPMENT OF A FRAMEWORK AND ANALYSIS SYSTEM TO SUPPORT INTERVENTION IN NEWBORN HEALTHCARE

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One of the most vulnerable populations in healthcare is the newborn infant. As hospitalization for childbirth is the largest cause for entry into a healthcare facility, the population of newborns each year is extensive as is their cost of care. Newborn infants also may have additional costs associated with readmission for common or preventable illnesses, which may occur due to insufficient infant screening or lack of caregiver knowledge. Much research has been done to attempt to determine causes of readmission, what contributes to an increased or decreased readmission rate among newborns, and how healthcare interventions can impact these rates and newborn health. Although many intervention types have been attempted, most of them have been centered on in-person education which can drastically increase costs and make a promising intervention non-cost effective.

Healthcare Systems engineering has its roots in the discipline of industrial engineering and allows for the use of statistical and analysis tools to identify problems and provide appropriate solutions. One of the main focuses of the healthcare industry is on providing cost-effective solutions that can improve patient outcomes. As healthcare personnel are notoriously understaffed and overworked, solutions need to be presented in a manner that they are both likely to be adopted by the practitioner and received well by the patient.

Using the existing research from the literature, several Ishikawa diagrams on readmission causes and factors were developed. The data from these diagrams was used to create forest plots for meta-analysis of existing literature, and a simulation model of readmission and mortality in newborn readmissions was developed. Additionally, a C based program has been developed to quickly calculate odds ratios and confidence limits for a given case study data set and store and retrieve information on individual factors.

The goal of this work is for healthcare professionals to have access to tools, the simulation and the program, which will allow them to quickly and easily access available data from the literature as well as their own studies to apply to intervention creation and testing in order to facilitate an analytical approach to newborn readmission.

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CHAPTER 1
INTRODUCTION

1.1 Overview

Approximately 10% of all admissions into U.S. hospitals are for childbirth. Because of this, the healthcare system, which is extremely complex and requires better utilization of resources in order to meet the taxing demands that have been placed upon it, views unplanned readmissions into hospitals as a further tax on an already straining system thereby reducing the ability of hospital personnel to meet patient demands. Some research has previously explored unplanned readmission and its relationship to the quality of care initially provided (Bennbassat & Taragin, 2000; Hofer & Hayward, 1995; Thomas & Holloway, 1991). Quality in the healthcare system has been defined as whether the right things are done at the right time and if they are done well (Brook & Lohr, 1985; Donabedian, 1980).

In the realm of research on unplanned readmissions for newborn infants, the literature is still relatively new. Study methods are typically severely limited and the quantitative values found are usually limited in statistical power. The quality of care of the newborn infant, however, is one of the most important areas of healthcare that could be potentially successfully addressed as it is the most common cause of hospitalization in the population. This research uses the current literature to analyze various factors and interventions that could influence newborn readmission with the goal of reducing readmission for preventable illnesses and reducing the readmission length of stay for unpreventable illnesses. In order to facilitate the faster and easier analysis of proposed or attempted interventions, Ishikawa diagrams have been created to better understand the relationships that have been found to be related to the various factors for readmission as documented in the literature. Using these factors, a simulation model was developed that will appropriately model readmission and mortality in order to assist decision makers with developing more informed intervention strategies at no risk or cost. This work will therefore allow for faster and easier analysis on proposed or attempted interventions via testing through the development of a simulation model and a C based program for case study data analysis and information storage and retrieval.

1.2 Motivation

Healthcare as an industry focuses on improving patient outcomes, but in today's society, it is necessary for healthcare organizations to also focus on financial outcomes as well. While many healthcare organizations might prefer to do whatever is necessary to prolong or improve quality of life, financial constraints may not allow for this. If a given program or solution is not cost effective, an organization can no longer afford to simply continue with such activities.

In the United States [U.S.], approximately 10% of all hospital stays are for childbirth (Pfuntner, 2013) with more than 3.9 million stays per year (Hamilton, Martin, Osterman, Curtin, & Mathews, 2015), making childbirth the most common cause for hospitalization in the U.S. Such hospitalizations are particularly costly to the healthcare industry and have been the focus of many efforts to attempt cost reduction since the late 1950s. The majority of these efforts, especially in earlier years, were focused on reducing length of stay [LOS] in the hospital for healthy mothers and infants after birth, but in more recent years, the research in this topic has been expanded to include dozens of studies and a wide variety of factors.

1.3 Research Questions

This research will focus on the following primary research questions: 1. What are the most common causes of newborn readmission and mortality? What factors relate to newborn readmission and mortality? How do they contribute to readmission and mortality? Can their effects be mitigated? This research is aimed at determining the main causes of newborn readmission and mortality and locating any relationships that may allow for the damaging effects to be removed or mitigated. 2. What is the most appropriate method for the dissemination of the results of Question 1 to healthcare professionals regarding infant healthcare programs such as interventions for primary caregivers and decision makers?

1.4 Research Objectives

The objective of this research is to identify and understand the causes and contributors to newborn infant adverse health outcomes, specifically, hospital readmission and mortality of the newborn infant in the first 28 days after birth. Additionally, the goal of this research is to propose a different method for approaching decision makers, practitioners, lean/six sigma teams, or process improvement teams, on the topic of newborn and infant health and to create a decision framework that educates someone to improve newborn and infant outcomes using a just in time approach to information delivery.

1.5 Contributions

The contributions of this research include:

1. Development of a Newborn Readmission Ishikawa Diagram that illustrates the relationship between readmission and a variety of causes as well as their contributing factors
2. Development of a Newborn Readmission Factors Associated with Decreased Readmission Risk Ishikawa Diagram that will illustrate the cause and effect relationship between a wide variety of factors from the literature and readmission of the newborn infant
3. Development of an Ishikawa Diagram of Newborn Readmission Factors Associated with Increased Readmission Risk that can be used to identify intervention strategies aimed at mitigating the effects of variables that significantly contribute to readmission
4. The development of forest plots to depict the meta-analysis of current literature for individual factors
5. A Newborn readmission and mortality simulator for intervention testing in order to model the cost effectiveness of intervention strategies without risk to infant life
6. A C Based Program for performing case study data analysis and information storage and retrieval

Table 1.5.1 includes the listed contributions along with their relationship to health systems engineering and the justification of the contribution to the current body of literature. The stake-holders that would benefit from this information include engineers, researchers, healthcare personnel, quality improvement specialists, and mothers, families, and infants.

Table 1.5.1 Research Contributions and Relationship to Healthcare Systems Engineering

Contribution	Relationship to Healthcare Systems Engineering	Justification
Newborn Readmission Ishikawa Diagram	An Ishikawa diagram is typically used to identify cause and effect relationships. Each component of the diagram allows for the identification of a factor the contributes to some outcome. Each cause can then be broken into many other components in an attempt to understand the true nature of the problem. Every cause or reason listed will be a source of variation and preventative action may not be possible for all components of the diagram.	The Ishikawa diagram for newborn readmission illustrated the major components that cause readmission. If these components can be understood and broken down into pieces, then the best methods for preventative interventions can be obtained. Understanding the causes of readmission and how they contribute to the problem will enable intervention strategies to be developed.
Newborn Readmission Factors Associated with Decreased Readmission Risk Ishikawa Diagram	An Ishikawa diagram is typically used to identify cause and effect relationships. Each component of the diagram allows for the identification of a factor the contributes to some outcome. Each cause can then be broken into many other components in an attempt to understand the true nature of the problem. Every cause or reason listed will be a source of variation and preventative action may not be possible for all components of the diagram.	The Ishikawa diagram for readmission factors associated with a decreased readmission risk will allow for an easy, visual method to determine the major contributing factors for decreased readmission found in the literature. This knowledge will allow for further, in-depth study to determine if any interventions may be applied to increase these effects where value can be obtained or decrease the effects when factors are associated with higher mortality caused from a lack of care.
Newborn Readmission Factors Associated with Increased Readmission Risk Ishikawa Diagram	An Ishikawa diagram is typically used to identify cause and effect relationships. Each component of the diagram allows for the identification of a factor the contributes to some outcome. Each cause can then be broken into many other components in an attempt to understand the true nature of the problem. Every cause or reason listed will be a source of variation and preventative action may not be possible for all components of the diagram.	The Ishikawa diagram for readmission factors associated with a increased readmission risk will allow for an easy, visual method to determine the major contributing factors for increased readmission found in the literature. This knowledge will allow further, in depth study to determine if any interventions may be applied to decrease these effects in a cost-effective manner.
Development of forest plots for factor meta-analysis	Forest plots allow for the pictorial representation of odds ratios and confidence limits. It also allows weighted averages of multiple studies to be identified and an overall result obtained.	The forest plot meta-analysis for individual factors will allow the user to quickly review a large number of studies to determine the quality of factor information and the usefulness of that information to be used in other intervention components.

Newborn readmission and mortality simulator for intervention testing	Simulation allows decision makers to determine the likely behavior of a system prior to implementation in order to evaluate and compare scenarios for use and cost effectiveness without risk or cost.	This simulation model will contain the major risk factors for readmission and mortality of the newborn infant and allow decision makers to evaluate different intervention methods without cost or risk.
C Based Program for performing data analysis and information storage and retrieval	Programming allows for an easy to use interface for decision makers to quickly input preselected characteristics in order to have easy access to detailed information	The C based program will provide an outlet for practitioners to enter information or data and to quickly and easily receive calculation results or access previously detailed information on readmission factors, causes, or other available data.

1.6 Organization

Chapter 1 of this dissertation provides an overview of the research area, motivation, and solution focuses. The research questions, goals, and contributions are also included. Information about the organization of this document is provided at the end of chapter 1.

Chapter 2 provides information on the previous research available that can be applied to assist with identifying the research focus and future contributions. The background will include information on the problem domain including newborn healthcare history and literature, engineering methods and applications to newborn healthcare, and intervention types and uses. Further background will be supplied for the research methodologies.

Chapter 3 describes the research design and method for answering the research questions.

Chapter 4 provides research results. This chapter includes the development of the Ishikawa Diagrams as well as the development of the forest plots and simulator architecture. Additionally, this chapter details a C based program for performing data analysis on case studies and information storage and retrieval for the obtained results.

Chapter 5 provides an overview of directions to pursue for future work in this area.

Chapter 6 provides an overview of the conclusions from this dissertation.

CHAPTER 2
LITERATURE REVIEW

This section contains information on the history of newborn healthcare research as well as an exhaustive overview of the previous research that is available in this field. This chapter will serve as the base for the proposed research and will be used in building elements of the simulation model. The literature is comprised of two parts with part one containing the background information on the problem domain and information related to the research findings and questions. The second part of the literature review provides an overview of the research methods that will be used in conjunction with the previous information in order to answer the research questions.

2.1 Problem Domain

The focus of this paper is the application of engineering methods on newborn infant healthcare. A broad overview of newborn literature was done and will be discussed in order to motivate the research opportunities. A high-level overview of engineering methods and applications will also be included along with its applications to newborn health systems. The discussion will then focus on a specific research opportunity using engineering methods for newborn healthcare improvement. The discussion will include an analysis of target audience, objectives, delivery methods, audience reception, applied engineering methods, and expansion capabilities.

2.1.1 Healthcare Definitions

There are a few terms that occur frequently in the research which will be defined here. From this point forward, it will be assumed that these terms have been adequately defined and understood when they appear in later use.

A newborn infant, or neonate, is a child under 28 days of age (WHO | Infant, Newborn, n.d.).

The American Academy of Pediatrics [AAP] defines early discharge as a stay of 48 hours or less after an uncomplicated vaginal delivery, and a very early discharge as a stay of 24 hours or less (American Academy of Pediatrics| Postpartum and follow-up care, 1992).

Healthy newborns are those infants that are born healthy or are only being observed for issues but no medical intervention or decision making is required ("Implementation of the ACA," n.d.).

Newborns that are born at 37 weeks or less shall be considered preterm. Those born at 38 to < 40 weeks will be considered late preterm, and infants born from 40 to < 42 weeks will be considered term. Neonates that are born at a period of 42 + weeks will be considered late term (Medline Plus, n.d.).

2.1.2 Newborn Healthcare

2.1.2.1 History of Newborn Healthcare in the U.S.

2.1.2.1.1 Reducing LOS and Demedicalizing Childbirth

Beginning in the 1970s, hospitals began using a reduced LOS to combat a variety of factors including a shortage of hospital beds, increasing costs and as a way to “demedicalize” childbirth (Declercq, 1999; Lock & Ray, 1999). The overall mean LOS for both vaginal births and caesarian sections began declining, and by 1992, the average LOS for vaginal births had decreased by 37% to stand at 2.6 days while the average for caesarian births decreased by 49% to stand at 4.0 days ("Trends of Length of Stay", 1995). The literature suggests that this trend may have begun in the mid-1970s in Kaiser Permanente in California (Yanover, Jones, & Miller, 1976), but it soon became the standard for hospitals to discharge termed ‘healthy’ newborns from the hospital with short, 48 hours or less, or even very short, less than 24 hours, length of stays. Following 1992, the trend continued with the average LOS shrinking even further. During this time, the terms ‘drive-through deliveries’ or ‘drive by deliveries’ were derived to describe the extremely short length of stays that many mothers felt they were experiencing (Declercq, 1999).

Proponents of a shortened LOS have posited that a reduced LOS can reduce the risk of iatrogenic infections, allow the mother and newborn to recover in a familiar home environment, and reduce the hospital costs of caring for the infant and mother (Danielsen, Castles, Damberg, & Goulds, 2000; Lee, Perlman, Ballantyne, Elliott, & To, 1996). Opponents of the policy argued that longer postpartum length of stays could help reduce the risk of certain diseases such as jaundice that do not manifest until 2 or more days after delivery (Datar & Sood, 2006; Farhat & Rajab, 2011; Lee, et al., 1996). A longer LOS would facilitate newborn screening for hereditary and congenital diseases and further the use of newborn screening tests (Datar & Sood, 2006; Lee, et al., 1996). Mothers would also be able to receive more training in proper infant care techniques, women's health, and breastfeeding (Datar & Sood, 2006; Lee, et al., 1996), which is often not established until the third postpartum day or later (Danielsen, et al., 2000; Datar & Sood, 2006; Lee, et al., 1996). As a number of horror stories emerged on the topic of 'drive-through deliveries,' where infants later developed life-threatening but potentially preventable conditions, public outrage spurred state legislatures to action (Arnold, 1995; Declercq, 1999; Eaton, 2001).

2.1.2.1.2 State and Federal Laws

In May 1995, the Maryland state legislature enacted the Mothers' and Infants' Health Security Act aimed at curtailing the 24-hour discharge policies in order to ensure sufficient infant feeding and adequate newborn screening for hereditary and congenital disorders (Md. Laws ch. 503., 1995). This law required insurance companies to provide coverage for maternity and newborn care "in accordance with the medical criteria outlined in the most current version of the Guidelines for Perinatal Care prepared by the American Academy of Pediatrics [AAP] and the American College of Obstetricians and Gynecologists [ACOG]" (Md. Laws ch. 503., 1995).

Later in June of 1995, New Jersey enacted a similar law, which unlike its Maryland counterpart, specified that insurance plans must pay for "a minimum of 48 hours of in-patient care following a vaginal delivery and a minimum of 96 hours of in-patient care following a caesarian section for a mother and her newly born child in a health care facility" (Ch. 138 Laws of New Jersey., 1995). North Carolina then became the third state to enact newborn legislation in July of 1995. This legislation stated that "a health benefit plan that provides maternity coverage shall provide coverage for inpatient care for a mother and her newly-born child for a minimum of forty-eight hours after vaginal delivery and a minimum of ninety-six hours after delivery by caesarian section" (N.C.S.B. 345, Sec 58-3-170., 1995). In November of the same year, Massachusetts signed legislation similar to the New Jersey law, and several other states including California, Connecticut, Delaware, Illinois, Kentucky, Michigan, New Mexico, New York, Ohio, Pennsylvania, Rhode Island, and Wisconsin had similar legislation pending or under study (Annas, 1995). At this time, the mean LOS for vaginal deliveries had dropped to 1.7 days ("Moms gaining time", 1999).

Shortly after New Jersey adopted their law, a similar law, "Newborns' and Mothers' Health Protection Act," was proposed at the federal level. President Bill Clinton signed the Newborns' and Mothers' Health Protection Act into law on September 26, 1996 where it would become effective on January 1, 1998. The Newborns' and Mothers' Health Protection Act of 1996 [NMHPA] mandated that insurance providers cover both mother and newborn for a 48 hour hospital stay after a vaginal delivery and at least a 96 hour stay after a caesarian delivery. The NMHPA required that any discharge before this time could be made by a physician only after consulting with the mother.

2.1.2.2 Newborn Readmission

2.1.2.2.1 Study Limitations

Newborn healthcare readmission rates typically range between 1.8% and 11.7% in the current literature (Conrad, 1989; Farhat & Rajab, 2011; Grupp-Phelan, Taylor, Liu, and Davis, 1999; Lock & Ray, 1999; Sword et al., 2001) and are attributed to a wide variety of causes. An analysis of the literature has produced several major categories in which the majority of readmissions are based. There is some difficulty in comparing various studies as most of the research does not focus on the same specific sets of causes. Many of the causes are given non-descriptive names or are grouped together in ways that are not similar to other studies. It is also very common for the literature to differ even in the time period over which the study was conducted.

The current literature sports a number of limitations based on study designs including selection bias using only low risk cases (Arthurton & Bamford, 1967; Britton, 1984; Carty & Bradley, 1990; Conrad, 1989; Hellman, Kohl, & Palmer, 1962; James & Hudson, 1987; Pittard & Geddes, 1987; Rush, 1993; Theobald, 1959; Welt, Cole, Myers, Sholes, & Jelovsek, 1993; Yanover, et al., 1976), selection for shortened stays by volunteer parents (Britton, 1984; Carty & Bradley, 1990; James & Hudson, 1987; Rush, 1993; Welt, et al., 1993; Yanover, et al., 1976), use of cointerventions preventing early discharge problems from escaping detection (Britton, 1984; Carty & Bradley, 1990; Conrad, 1989; Hellman, et al., 1962; James & Hudson, 1987; Pittard & Geddes, 1987; Rush, 1993; Welt, et al., 1993; Yanover, et al., 1976), and insufficient statistical power (Britton, 1984; Carty & Bradley, 1990; Conrad, 1989; Hellman, et al., 1962; James & Hudson, 1987; Pittard & Geddes, 1987; Rush, 1993; Theobald, 1959; Welt, et al., 1993; Yanover, et al., 1976). Many of the causes and factors that are studied are also either broken into extremely small or extremely broad categories, which can make cross comparison difficult. In addition the literature also varies from study to study on metrics with some studies using metrics that appear to be non-standard for this subject area such as risk ratios rather than odds ratios. Other limitations of newborn studies include protocol violations and withdrawals and the loss of patients for follow-up (Brown, Small, Argus, Davis, & Krastev, 2002).

2.1.2.2.2 Readmission Causes

Table 2.1.2.2.2.1 provides an overview of the distribution of time periods that have recently been studied with relation to newborn readmission causes. This distribution is important as it shows the differences in the definition of 'Newborn' that are used across studies. The majority of the literature, however, seems to agree on the more common definition of a newborn as an infant from birth to 28 days (Danielsen, et al., 2000; Ellberg et al., 2008; Farhat & Rajab, 2011; Gazmararian & Koplan, 1996; Liu, et al., 2000; Meikle, Lyons, Hulac, & Orleans, 1998; Tomaskek et al., 2006; Young, Korgenski, & Buchi, 2013).

Table 2.1.2.2.2.1 Distribution of Time Intervals from Literature Analysis

Time Intervals				
0 - 14 Days	0 - 21 Days	0 - 28 Days	0 - 30 Days	0 - 42 Days
Escobar et al. 2005 Lee, et al., 1996 Maisels & Kring, 1998	Soskolne, 1996	Danielsen, et al., 2000 Ellberg et al., 2008 Farhat & Rajab, 2011 Gazmararian & Koplan, 1996 Liu, et al., 2000 Meikle, et al., 1998 Tomaskek et al., 2006 Young, et al., 2013	Lock & Ray, 1999	Martens et al., 2004

2.1.2.2.2.1 Jaundice/Hyperbilirubinemia

The most commonly agreed on cause for readmission among the literature is the presence of jaundice or hyperbilirubinemia in the newborn. Jaundice is the yellowing of the skin, sclerae, and other tissues due to the accumulation of the yellow-ish pigment bilirubin (Cohen, Wong, & Stevenson, 2010). It is not a singular disease, and therefore, has no specific cause. Preventative measures such as blood exchange transfusions and phototherapy are usually nonspecific and aimed at removing the bilirubin after its production before it can accumulate in excess (Cohen, et al., 2010). Readmissions for jaundice occurred in 13 of the studies that contained data for readmission causes. Readmission rates for jaundice or hyperbilirubinemia ranged from 8% to 84.2% of all readmissions in 10 of the studies (Ellberg et al., 2008; Escobar et al. 2005; Farhat & Rajab, 2011; Gazmararian & Koplan, 1996; Lock & Ray, 1999; Maisels & Kring, 1998; Martens et al., 2004; Soskolne, 1996; Tomaskek et al., 2006; Young, et al., 2013) and accounted for a range of 4.2 per 1000 readmissions to 16.44 per 1000 readmissions in four studies (Danielsen, et al., 2000; Lee, et al., 1996; Liu, et al., 2000; Maisels & Kring, 1998).

If left untreated jaundice can cause complications with the newborn infant. Acute bilirubin encephalopathy is a condition where bilirubin passes into the brain. Bilirubin is toxic to brain cells and, without prompt treatment, may cause lasting damage. Indicators of acute bilirubin encephalopathy may be listlessness or difficulty waking, high-pitched crying, poor sucking or feeding, backward arching of the neck or body, fever, and vomiting (Mayo Clinic | Infant jaundice complications, 2014). If the brain is permanently damaged, Kernicterus is said to have occurred. Kernicterus may result in involuntary and uncontrolled movements, a permanent upward gaze, hearing loss, and improper development of tooth enamel (Mayo Clinic | Infant jaundice complications, 2014).

The AAP established a series of guidelines to direct healthcare providers towards the appropriate testing and treatment measures for the newborn infant at risk for jaundice. Newman, Xiong, Gonzales, & Escobar, however, found that only 33% of infants in their cohort with elevated bilirubin levels that exceeded the treatment threshold were exposed to a phototherapy intervention within the designated eight hours. Newman, et al. posited that this could very well be because many clinicians are unaware that these guidelines exist (Newman, et al., 2000).

2.1.2.2.2.2 Dehydration, Failure to Thrive, and Other Feeding Related Issues

The second most common cause of readmission cited throughout a variety of studies was dehydration, failure to thrive, and other feeding related difficulties. Feeding issues are much more difficult to clearly compare across studies than the previous readmission cause of jaundice. Among a series of 11 studies, five different labels were used to describe these issues including feeding related, dehydration, dehydration/failure to thrive, failure to thrive, and dehydration/fever (Danielsen, et al., 2000; Ellberg et al., 2008; Escobar et al. 2005; Liu, et al., 2000; Lock & Ray, 1999; Maisels & Kring, 1998; Martens et al., 2004; Meikle, et al., 1998; Soskolne, 1996; Tomaskek et al., 2006; Young, et al., 2013). From this point forward, all of these labels will be grouped into a singular label of dehydration, failure to thrive, and other feeding related issues. Across nine studies, readmission rates for this cause ranged between 0.28% and 40.9% (Ellberg et al., 2008; Escobar et al. 2005; Lock & Ray, 1999; Maisels & Kring, 1998; Martens et al., 2004; Meikle, et al., 1998; Soskolne, 1996; Tomaskek et al., 2006; Young, et al., 2013) and ranged from 0.2 readmissions per 1000 to 10.46 readmissions per 1000 across three studies (Danielsen, et al., 2000; Liu, et al., 2000; Maisels & Kring, 1998).

2.1.2.2.2.3 Infectious, Parasitic, and Respiratory Illnesses

As in the previous section, this category is comprised of seven different labels from a total of seven studies including infectious or respiratory diseases, infectious or parasitic diseases, respiratory illness, viral or respiratory illness, and respiratory distress with these types of illnesses ranging from .65% of the readmission population to 50.7% of the study population (Farhat & Rajab, 2011; Gazmararian & Koplan, 1996; Lock & Ray, 1999; Martens et al., 2004; Meikle, et al., 1998; Tomaskek et al., 2006; Young, et al., 2013).

2.1.2.2.2.4 Infections

Infections, typically allocated between low, medium, and high risk, were all grouped together in a single category. Six studies were conducted in which infections were found to be present, and readmission rates ranged from 2.8% to 43% (Ellberg et al., 2008; Meikle, et al., 1998; Tomaskek et al., 2006; Young, et al., 2013). Additionally, readmission rates of 0.2 per 1000 readmissions to 10.13 per 1000 readmissions were found (Danielsen, et al., 2000; Maisels & Kring, 1998).

2.1.2.2.2.5 Rule Out Sepsis

Infant related sepsis is an infection of the blood that typically occurs in an infant that is younger than 90 days old. Neonatal sepsis is caused by bacteria such as Escherichia coli [E.coli], Listeria, herpes simplex virus [HPV] or some strains of streptococcus. Early onset sepsis usually occurs between birth and 3 months of age (Lee, 2015). From the literature, 7 studies included sepsis or rule out sepsis as a cause for readmission. Ranges from 10.1% to 30% of the readmission population occurred in six studies (Escobar et al. 2005; Farhat & Rajab, 2011; Maisels & Kring, 1998; Soskolne, 1996; Tomaskek et al., 2006; Young, et al., 2013) and 2.34 readmissions per 1000 to 2.4 readmissions per 1000 in two studies (Liu, et al., 2000; Maisels & Kring, 1998).

An infant can have an improved likelihood for readmission for early onset sepsis if there was Group B streptococcus [GBS] colonization during pregnancy, preterm delivery, premature rupture of membranes (i.e. water breaking longer than 18 hours before birth), or infection of the placenta tissues or amniotic fluid. Late-onset neonatal sepsis is where the infant is infected after delivery, and the factor most associated with a risk of contracting late-onset sepsis is an extensive hospital stay (Lee, 2015).

Infants with neonatal sepsis will often display with body temperature changes, breathing difficulties, diarrhea or decreased bowel movements, low blood sugar, reduced movement, decreased sucking, seizures, abnormal heart rate, swollen abdominal area, vomiting, or jaundice (Lee, 2015). Blood cultures, C-reactive protein, or a Complete blood count [CBC] may be used to identify the cause of an infection. Chest x-rays may also be done if the infant exhibits difficulty breathing, and urine cultures can be done in babies older than a few days (Lee, 2015). While immediate treatment is likely to produce positive outcomes, a lengthy delay in identification or treatment of sepsis can lead to disability or death (Lee, 2015).

2.1.2.2.2.6 Congenital Anomalies

A review of the literature shows that newborn studies have typically broken this category down into two main components, Congenital Cardiac Defects, and Congenital/Lower Bowel Obstructions, with the addition of a third label, Congenital Anomalies that contains both along with any other type of congenital malformation. From this point forward, congenital anomalies will be used to indicate the presence of one or more congenital defects including the congenital heart and congenital bowel anomalies. A total of eight studies have evaluated the incidence of readmissions caused by congenital defects that were missed prior to discharge from the hospital. The readmission rates range from 2% of the readmission population to 10.4% (Ellberg et al., 2008; Gazmararian & Koplan, 1996; Martens et al., 2004; Meikle, et al., 1998; Soskolne, 1996; Tomaskek et al., 2006) and from .14 readmissions per 1000 to .42 readmissions per 1000 (Danielsen, et al., 2000; Lee, et al., 1996)

According to the World Health Organization [WHO], more than 300,000 newborns die within the first month of life each year, worldwide, due to congenital anomalies (WHO | Congenital anomalies, 2016). Congenital anomalies can cause disability or death if not treated. The most common severe congenital anomalies are heart defects, neural tube defects, and Down syndrome (WHO | Congenital anomalies, 2016). Danielsen, et al. (2000) found that congenital anomalies were more likely to be significantly contributing factors for readmission in those infants that were discharged very early versus those that were discharged early or later. Another study by Wren, Richmond, & Donaldson (1999) found that congenital heart disease is only diagnosed in less than half of all affected infants prior to initial discharge. Meanwhile, Mellander & Sunnegårdh (2007) found that 19.7% of infants had critical heart malformations that were undiagnosed before leaving the hospital, and that 75% of those missed diagnoses were defects with duct-dependent systemic circulation. Two other studies have reported similar findings (Abu-Harb, Hey, & Wren, 1994; Abu-

Harb, Wyllie, Hey, Richmond, & Wren, 1994). A study of a Norwegian cohort, however, produced very few missed diagnoses (Meberg, Otterstad, Fröland, Hals, & Sorland, 1999).

In an attempt to address the issue of missed congenital anomalies, specifically Critical Congenital Heart Defects [CCHD], several studies have attempted to use pulse oximetry to screen for duct-dependent heart disease, but have only managed minimal sensitivity (Koppel et al., 2003; Reich et al., 2003; Richmond, Reay, & Harb, 2002), although, a more recent study has paired a new-generation pulse oximeter with criteria of saturations in hand and foot (Granelli, Mellander, Sunnegårdh & Östman-Smith, 2007). Testing of the sensitivity and usefulness of pulse oximetry in the routine newborn exam would require larger studies than those presently available in the literature (Mellander & Sunnegårdh, 2007). In 2010, the Sixty-third World Health Assembly agreed to focus its efforts on the reduction of the loss of life through congenital malformations by aiming to improve intervention and prevention strategies and rigorously studying methods to improve testing and treatment (WHO | Congenital anomalies, 2016).

2.1.2.2.2.7 Other/Miscellaneous/Ill Defined Readmission Causes

Several other causes of newborn readmission were specifically noted in one or more studies and included severe or prolonged illness (Escobar et al. 2005), anatomic or metabolic illnesses (Lee, et al., 1996; Lock & Ray, 1999), and apnea, cyanosis, seizure, or other life threatening event (Maisels & Kring, 1998; Soskolne, 1996). Several studies also included extremely specific labels with limited incidence rates, so any remaining diagnoses were added to create the final category most often depicted in the literature as Other/Miscellaneous/Ill Defined with readmission rates for this specific notation ranging from .28% to 51.7% (Ellberg et al., 2008; Escobar et al. 2005; Gazmararian & Koplan, 1996; Lock & Ray, 1999; Maisels & Kring, 1998; Martens et al., 2004; Meikle, et al., 1998; Soskolne, 1996; Tomaskek et al., 2006) and rates per 1000 of .6 to 10.7 (Danielsen, et al., 2000; Lee, et al., 1996; Maisels & Kring, 1998).

2.1.2.2.3 Readmission Factors

A thorough review of the literature produced a wide variety of factors that have been studied in relation to the likelihood for readmission of the newborn infant. Many of the factors studied were only found in a single study, but there were also several factors that were widely used. As previously mentioned, comparing factors from study to study is rather difficult as the studies often occurred over differing time periods. Although many of the studies observed the same general factors, they parsed them into many different sub-factors, and almost no two studies parsed sub-factors into the same categories. For the purpose of this review, broad categories of maternal, pregnancy, delivery, infant, and hospital characteristics were used to divide the differing types of factors found. Within each of these five categories, several further categories were used to separate the literature into related parts. Furthermore, each study used one or more of the same three methods, ratios, confidence limits, and p-values, to quantify the relationships between each readmission factor and readmission odds. For simplicity these three measures will be related for each factor as (Odds Ratio)(Confidence Limits)(p-value) with (*) used to denote that a value was not calculated for the study.

2.1.2.2.3.1 Maternal Characteristics

2.1.2.2.3.1.1 Parity/Marital Status

Parity refers to the number of parents in the household. A multiparous household will contain two parents, and a primiparous household will contain only one parent, the mother. Three studies focused on parity. One used Primiparity as the reference value and obtained the following measures (OR 0.794)(CL 0.388, 0.624)(p-value 0.53) (Farhat & Rajab, 2011), while the second and third studies reversed the reference and found (OR 1.21)(CL 1.15, 1.27)(p-value *) (Danielsen, et al., 2000) and (OR 1.75)(CL 1.59, 1.93)(p-value <.001) (Paul, Lehman, Hollenbeak, & Maisels, 2006). Although the methods were slightly different, all three studies agreed that using confidence limits an infant born to a primiparous household was more likely to require readmission. Farhat and Rajab (2011), however, found that parity was not a significant factor using p-values, whereas Paul, et al. (2006) did find parity to be significant at the <.001 level.

Along with parity, a couple of studies also focused on the marital status to determine what, if any, association there was for readmission. Danielsen, et al. (2000) found (OR 1.01)(CL 0.96, 1.06)(p-value *) using Married as the reference, whereas Paul, et al. (2006) found (OR 1.38)(CL 1.24, 1.54)(p-value <.001) using single as a reference. Only the latter study found marital status to be likely to be related to readmission by means of either the confidence limits or the p-value.

2.1.2.2.3.1.2 Maternal Age

One of the more commonly studied factors for readmission was maternal age. Three studies each sub-divided maternal age into different categories. Escobar et al. (2005) used three categories < 18 years, 18-34 years old, and 35+ years to divide maternal age. Using 18-34 years old as the reference category, they found the following: < 18 years (OR 0.98)(CL 0.6, 1.61)(p-value *) and 35+ years (OR 1.05)(CL 0.87, 1.26)(p-value *) (Escobar et al., 2005). Danielsen, et al. (2000) subdivided maternal age into four categories with 20 - 30 years as the reference category and obtained the following: <18 years (OR 0.99)(CL 0.89, 1.10)(p-value *), 18 - 20 years (OR 1.02)(CL 0.93,1.1)(p-value *), and 30+ years (OR 1.03)(CL 0.98, 1.09)(p-value *). Paul, et al. (2006) also studied maternal age, but they used the overarching factor of maternal age to obtain significance with a p-value of 0.002. They further divided the age category into 7 parts with 25 - 29 years as the reference: < 15 years (OR 0.24)(CL 0.03, 1.04)(p-value *), 15 - 19 years (OR 0.78)(CL 0.64, 0.95)(p-value *), 20 - 24 years (OR 0.88)(CL 0.77, 1.01)(p-value *), 30 - 34 years (OR 1.01)(CL 0.89, 1.15)(p-value *), 35 - 39 years (OR 1.02)(CL 0.87, 1.19)(p-value *), and 40+ years (OR 1.48)(CL 1.09, 2.02)(p-value *).

Of these studies, only the study by Paul, et al. (2006) found maternal age to be associated with increased or decreased readmission among newborns. Infants born to mothers of 15 - 19 years showed a decreased likelihood to be readmitted, perhaps because they are developed enough to give birth with minimal complications but may still reside at home with their own more experienced parent. Maternal age of 40+ years showed an increased likelihood for readmission, which is perhaps not surprising as older mothers are more prone to complications and advanced maternal age is associated with an increased risk of congenital malformations. Figure 2.1.2.2.3.1.2.1 below shows the distribution of mother's age at birth for 2014.

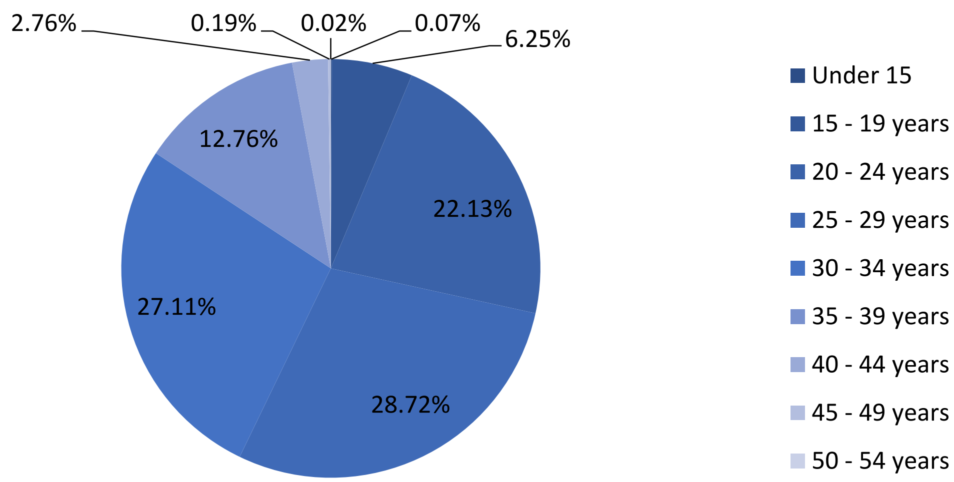

Figure 2.1.2.2.3.1.2.1 Percent Distribution of Mother's Age at Time of Labor: U.S., 2014 (Hamilton, et al., 2015)

2.1.2.2.3.1.3 Maternal Education

Maternal education was studied among two cohorts. Paul, et al. (2006) found maternal education to be significant with a p-value of <.001 and categorized education level into three levels with No College Education as the reference: Some College (OR 1.32)(CL 1.17, 1.49)(p-value *) and At Least 4 years of College (OR 1.63)(CL 1.46, 1.83)(p-value *). Danielsen, et al., (2000) also studied maternal education but used only two categories, the reference category, High School +, and < High School Education (OR 1.00)(CL 0.94, 1.06)(p-value *). Of these two studies, only Paul, et al. (2006) found that an increased maternal education level was also likely to increase the likelihood of readmission. This may seem counterintuitive, but Paul, et al. posited that parents with a higher education level will likely have an appropriately increasing income thereby allowing parents to get their infant the care they need whereas less educated mothers may not have the ability to afford further postnatal care.

2.1.2.2.3.1.4 Birthplace of Mother

One study also briefly touched on the issue of maternal birth location in order to further understand how likely immigrants to the U.S. would be to seek care for their infants in the event of an issue. Danielsen, et al. (2000) found that compared to U.S. born mothers, the reference, infants of foreign born mothers were less likely to be readmitted (OR 0.92)(CL 0.87, 0.98)(p-value *). Danielsen, et al. also suggested that this may be because of a larger population of illegal immigrants in the study population who may not have had insurance and therefore could not afford further health care for their newborn.

2.1.2.2.3.1.5 Income/Insurance

Sword et al. (2001) investigated the source of household income and its relationship to newborn readmission. Using Salary/Self-Employment as the reference, they found that other sources of income (i.e. day labor, child support, welfare) were more likely to increase readmission (OR 4.26)(CL 1,94, 9.35)(p-value *) (Sword et al., 2001). Along with income, several studies also investigated insurance types with readmission. Paul, et al. (2006) found insurance type to be significant with a p-value of <.001. With private insurance as the reference, Paul, et al. studied Medicaid (OR 0.78)(CL 0.70, 0.88)(p-value *), Other Insurance Types (OR 1.19)(CL 0.68, 2.08)(p-value *) and No Insurance (OR 0.98)(CL 0.68, 2.08)(p-value *). Danielsen, et al. (2000) also used private insurance as the reference against MediCal (OR 1.23)(CL 1.12, 1.37)(p-value *), Self-Pay (OR 0.74)(CL 0.63, 0.87)(p-value *), and Health Maintenance Organizations (OR 1.05)(CL 0.96, 1.16)(p-value *). Of these two studies, mothers using Medicaid or Self-Pay were less likely to be readmitted while mothers with MediCal were more likely to be readmitted (Danielsen, et al., 2000; Paul, et al., 2006).

2.1.2.2.3.1.6 Mother's Rating of Competence, Health and Support

Sword et al. (2001) studied the mother's rating of her own health with Excellent/Very Good/Good/Fair as the reference against a rating of Poor (OR 5.17)(CL 1.70, 15.73)(p-value *) and found an increased likelihood for readmission if the mother felt her own health was suffering. This is likely caused because the mother may require additional help that she cannot receive at home in order to adequately care for her infant. Infants born to mothers in poor health may also suffer from difficult births which could increase their risk of readmission for a variety of reasons.

Sword et al. (2001) also suggested home support as an area of interest and determined that mothers that believed they did not have adequate support at home were more likely to be readmitted (OR 3.17)(CL 1.48, 6.82)(p-value *) compared to those who responded that their home support was sufficient. If the mother was to receive unpaid or informal help from a friend or neighbor, the infant was also more likely to be readmitted for all causes (OR 2.7)(CL 1.26, 5.79)(p-value *) than those who did not receive help from others outside the household (Sword et al., 2001). These infants may be readmitted at an increased frequency given that they associate with a larger number of people and may be at risk for a number of transmittable illnesses.

Two studies were also done in relation to maternal competence. One study by Johnson, Jin, and Truman (2002) found that if the infant was the first live birth for the mother (OR 1.68)(CL 1.54, 1.84)(p-value *), they were more likely to require readmission. Sword et al. (2001) determined that if a mother had concerns about infant care or behavior (OR 2.35)(CL 1.12, 4.91)(p-value *), the newborn was likely to have an increased rate of readmission.

2.1.2.2.3.1.7 Maternal Disease or Complications

Maternal disease and/or complications has been studied in many forms. Four studies have attempted to tackle understanding maternal complications and their relationship with newborn readmission. Farhat and Rajab (2011) found that if a maternal complication (OR 1.99)(CL 1.96, 2.10)(p-value 0.05) or disease (OR 2.00)(CL 1.01, 1.98)(p-value 0.004) was present then the infant was more likely to be readmitted. Danielsen, et al. (2000) also found that one or more complications was likely to increase readmission chances (OR 1.11)(CL 1.06, 1.16)(p-value *).

Paul, et al. (2006) also sub-divided six different types of maternal diseases or complications to include: maternal diabetes (OR 1.88)(CL 1.47, 2.41)(p-value 0.47), maternal hypertension (OR 1.56)(CL 1.03, 2.35)(p-value 0.03), pregnancy induced hypertension (OR 1.67)(CL 1.33, 2.09)(p-value <.001), premature rupture of membranes (OR 2.03)(CL 1.61, 2.57)(p-value <.001), and maternal alcohol use during pregnancy (OR 0.59)(CL 0.36, 0.96)(p-value 0.03). Their sixth sub-category, maternal smoking during pregnancy (OR 0.51)(CL 0.44, 0.59)(p-value <.001), was also studied by Maisels & Kring (1998) (OR 0.36)(CL 0.18, 0.71)(p-value .005).

Of these factors, maternal hypertension, pregnancy induced hypertension, and premature rupture of membranes were found to increase the risk of readmission while tobacco and alcohol use were found to reduce the likelihood for readmission. One study suggests that the relationship between pregnancy induced hypertension and readmission may be caused by treating the condition with magnesium sulfate which may decrease the effectiveness of breastfeeding and slow gastrointestinal motility in the infant thereby increasing the enterhepatic circulation of bilirubin (Lantzy, 2015; Maisels, MacDonald, Seshia, & Mullett, 2005). It has also been proposed that the relationship between alcohol and tobacco use of the mother may cause the mother to want to remain out of a healthcare facility where these activities would be curtailed, which might lead to a decreased likelihood of such mothers seeking further neonatal care (Maisels & Kring, 1998; Paul, et al., 2006). Relationships between the other factors and infant readmission remain moderately unclear, although, in some cases, it may be caused by the simultaneous readmission of both mother and infant.

2.1.2.2.3.2 Delivery Characteristics

2.1.2.2.3.2.1 Delivery Mode

Delivery mode is the most commonly studied delivery characteristic. Farhat and Rajab (2011) found vaginal delivery (OR 2.1)(CL 1.02, 4.34)(p-value 0.04) increased the incidence of readmission compared with cesarean delivery. Paul, et al. (2006) found delivery mode to be statistically significant with an overarching p-value of <.001; however, their results conflicted with those found by Martens et al. (2004) with Paul, et al.'s study indicating a decreased incidence of readmission for cesarean birth compared to vaginal birth(OR 0.37)(CL 0.31, 0.43)(p-value *) and Martens et al.'s finding the opposite (OR 1.22)(CL 1.10, 1.34)(p-value <.001). The distribution of delivery mode for 2014 can be seen in Figure 2.1.2.2.3.2.1.1 below.

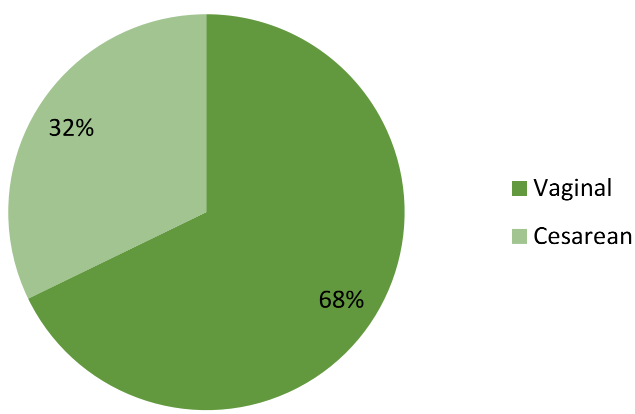

Figure 2.1.2.2.3.2.1.1 Distribution of Delivery Mode: U.S., 2014 (Hamilton, et al., 2015)

2.1.2.2.3.2.2 Medical Assistance

Limited information is available in the literature on the use of medical assistance during labor. One study found that forceps assisted deliveries (OR 1.60)(CL 1.25, 2.07)(p-value <.001) and vacuum assisted deliveries (OR 2.64)(CL 2.28, 3.07)(p-value <.001) were both more likely to significantly increase the probability of readmission (Paul, et al., 2006). Another study found that the use of oxytocin during labor (OR 0.72)(CL 0.29, 0.77)(p-value 0.47) may actually decrease the risk for readmission (Farhat & Rajab, 2011), but the results were not statistically significant. Further studies will need to be conducted to completely explore the relationship between medical assistance during labor and readmission in order to determine its affects on the newborn and improve future outcomes.

2.1.2.2.3.3 Infant Characteristics

2.1.2.2.3.3.1 Gestational Age

Among infant characteristics, gestational age is both the most widely studied and the most widely varied Figure 2.1.2.2.3.3.1.1 shows the distribution of gestational ages for U.S. births in 2014 below.

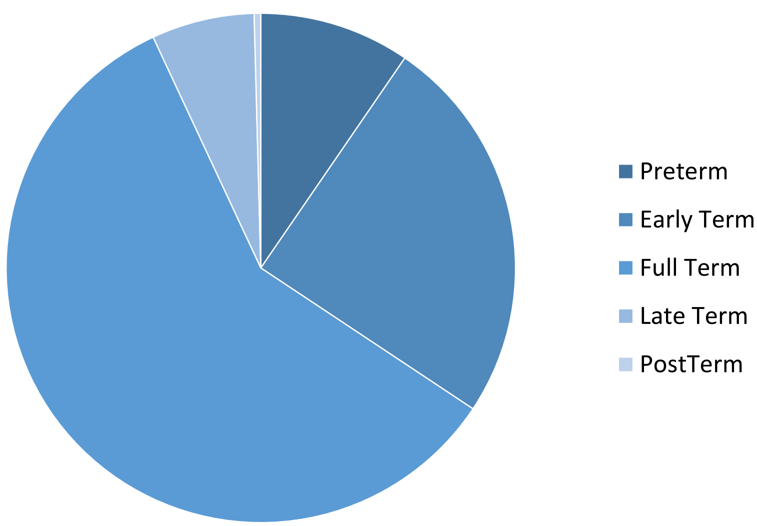

Figure 2.1.2.2.3.3.1.1: Distribution of Infant Gestational Age: U.S., 2014 (Hamilton, et al., 2015)

Paul, et al. (2006) found gestational age to be significant with a p-value of <.001 and divided it into four categories with 39 - 40 weeks as the reference: 35 - 36 weeks (OR 5.96)(CL 4.96, 7.16)(p-value *), 37 - 38 weeks (OR 2.52)(CL 2.26, 2.81)(p-value *), and 41+ weeks (OR 0.65)(CL 0.54, 0.79)(p-value *). Martens et al. (2004) and Farhat and Rajab (2011) both sub-divided this category into two, 37 weeks or less and > 37 weeks with > 37 weeks as the reference for the respective results of (OR 1.8)(CL 1.55, 2.07)(p-value <.001) and (OR 3.11)(CL 1.45, 6.64)(p-value .002). Tomaskek et al. (2006) used risk ratios rather than odds rations and found (RR 1.80)(CL 1.30, 2.50)(p-value *) for late preterm infants versus their term counterparts. and Johnson, et al. (2002) compared preterm, less than 37 weeks (reference), with 37 - 42 weeks, term, (OR 0.29)(CL 0.25, 0.34)(p-value *) and, post term, > 42 weeks (OR 0.43)(CL 0.10, 1.84)(p-value *). Another study partitioned gestational age even further into nine categories with the term infant, 40 weeks, as the reference: 34 weeks (OR 2.7)(CL 2.1, 3.5)(p-value .000), 35 weeks (OR 3.0)(CL 2.6, 3.6)(p-value .000), 36 weeks (OR 2.5)(CL 2.2, 2.8)(p-value .000), 37 weeks (OR 1.9)(CL 1.7, 2.1)(p-value .000), 38 weeks (OR 1.4)(CL 1.3, 1.5)(p-value .000), 39 weeks (OR 1.2)(CL 1.1, 1.3)(p-value .001), 41 weeks (OR 1.0)(CL 0.9, 1.2)(p-value .666), and 42 weeks (OR 0.8)(CL 0.3, 2.2)(p-value .680) (Young, et al., 2013). In every study, gestational age was found to be a significant indicator for readmission risk in at least one subdivision.

2.1.2.2.3.3.2 Birth Weight

Newborn birth weight is another factor that was found commonly between several studies. Farhat and Rajab (2011), Martens et al. (2004), and Danielsen, et al. (2000) all compared weights of < 2500 grams against those of > 2500 grams and found (OR 3.25)(CL 1.24, 8.52)(p-value 0.01), (OR 1.17)(CL 0.98, 1.40)(p-value *), and (OR 1.53)(CL 1.28, 1.82)(p-value *) respectively. Paul, et al. (2006) also studied newborn birth weight but divided it into seven categories with 3000 - 3499 grams as the reference: 1800 - 1999 grams (OR 2.82)(CL 0.89, 8.90)(p-value *), 2000 - 2499 grams (OR 1.51)(CL 1.15, 1.99)(p-value *), 2500 - 2999 grams (OR 1.44)(CL 1.26, 1.64)(p-value *), 3500 - 3999 grams (OR 0.83)(CL 0.73, 0.93)(p-value *), 4000 - 4499 grams (OR 0.82)(CL 0.68, 0.99)(p-value *), and 4500+ grams (OR 0.79)(CL 0.52, 1.21)(p-value *). Of these only three found one or more weight categories to be significant. Another study by Escobar et al. (2005) determined that infants that were considered small for their gestational age (OR 1.76)(CL 1.07, 2.91)(p-value *) were more likely to be readmitted than those of average weights.

2.1.2.2.3.3.3 Apgar Scoring

Another factor studied by Paul, et al. (2006) was the Apgar scores of the infant at both 1 and 5 minutes. The Apgar score is used to asses a newborn's condition at birth and is tested after the letters of its name: Activity, pulse, grimace, appearance, and respiration (Baby Center| The Apgar score, n.d.). Apgar scores are taken at both 1 and 5 minutes as was the case in Paul, et al.'s study. Scores between 0 - 3 mean the infant may need immediate life saving intervention, 3 - 6 indicate the infant may need assistance breathing, and scores of 7 - 10 indicate the infant is healthy (Baby Center| The Apgar score, n.d.). Paul et al. found that infants with an Apgar score of 8 or less at either 1 minute (OR 1.19)(CL 1.08, 1.31)(p-value <.001) or 5 minutes (OR 1.39)(CL 1.14, 1.70)(p-value .001) were more likely to require readmission .

2.1.2.2.3.3.4 Gender

Infant gender was studied in five cases. In three of the cohorts, female gender was compared to the reference of male gender. Farhat and Rajab (2011), (OR 0.92)(CL 0.48, 1.79)(p-value 0.8), did not find an association with readmission; however, both Johnson, et al. (2002) (OR 1.33)(CL 1.21, 1.45)(p-value *) and Paul, et al. (2006) (OR 0.75)(CL 0.68, 0.82)(p-value <.001) did, albeit in opposite directions. Two other studies compared the male gender to the referenced female gender and both found indications of increased readmissions related to male gender (OR 1.28)(CL 1.11, 1.49)(p-value *) (Escobar et al., 2005) and (OR 1.58)(CL 1.07, 2.34)(p-value .013) (Maisels & Kring, 1998).

2.1.2.2.3.3.5 Race

Compared to the Caucasian race, African Americans were found to have a decreased incidence of readmission (OR 0.61)(CL 0.43, 0.86)(p-value *) (Escobar et al., 2005), (OR 0.82)(CL 0.74, 0.92)(p-value *) (Danielsen, et al., 2000), and (OR 0.79)(CL 0.67, 0.93)(p-value *) (Paul, et al., 2006), which is typically attributed the decreased bilirubin levels usually found in infants of African American decent. Although Hispanic infants were studied in two cases, neither could conclude a relationship with readmission, (OR 1.10)(CL 0.90, 1.35)(p-value *) (Escobar et al., 2005) and (OR 1.04)(CL 0.98, 1.11)(p-value *) (Danielsen, et al., 2000). Danielsen, et al. also did not find a relationship between readmission and American Indian decent (OR 0.95)(CL 0.69, 1.31)(p-value *). Asian race/ethnicity has been studied in several forms. One study found that Asian infants were more likely to be readmitted due to higher bilirubin production rates making them more prone to jaundice (OR 1.49)(CL 1.22, 1.82)(p-value *) (Escobar et al. 2005). Two other studies found (OR 1.60)(CL 1.24, 2.06)(p-value *) (Paul, et al., 2006) and (OR 1.38)(CL 1.25, 1.53)(p-value *) (Danielsen, et al., 2000) whereby both found the same for Asian or Pacific Islanders and Other Asians respectively. Danielsen, et al., on the other hand, did not find an increase in readmission for Southeast Asian infants (OR 0.96)(CL 0.81, 1.13)(p-value *). Asian infants typically have higher bilirubin levels and has been found to increase the risk of readmission (Danielsen, et al., 2000; Escobar et al. 2005; Maisels, 1988; Newman, et al., 2000; Paul, et al., 2006; Setia, Villavaces, Dhillon, & Mueller, 2002,). An additional study by Setia, et al. (2002) found that infants with Asian fathers but white mothers were more at risk for readmission with jaundice than those born to Asian mothers with white fathers indicating that there may be some paternal factors at play as well. All other races were grouped together in the three studies, but no further relationships were found (Danielsen, et al., 2000; Escobar et al. 2005; Paul, et al., 2006).

2.1.2.2.3.3.6 Length of Stay

Paul, et al. (2006) found that length of stay was a significant indicator of readmission with a p-value of <.001. Their study contained 5 subdivisions of LOS with 48 to < 72 hours as the reference: < 24 hours (OR 0.6)(CL 0.34, 1.06)(p-value *), 24 to < 48 hours (OR 1.01)(CL 0.91, 1.12)(p-value *), 72 to < 96 hours (OR 0.40)(CL 0.32, 0.50)(p-value *), and 96+ hours (OR 0.39)(CL 0.27, 0.56)(p-value *). Of these only stays of 72 to < 96 hours and 96+ hours were related to decreased readmission. None of the time periods were found to be related to increased instances of readmission. In contrast Farhat and Rajab (2011) found that when compared against infants discharged after 48 hours, infants discharge at 48 hours or before (OR 5.20)(CL 1.81, 14.091)(p-value .001) were more likely to be readmitted. A third study by Hellman, et al. (1962) found no indication of a relationship between a LOS of 3 days or less compared with a > 3 day LOS. Another study found that very early discharge, 24 hours or less, increased the odds of readmission (OR 1.30)(CL 1.18, 1.43)(p-value *) and early discharge, between 24 and 48 hours, was not found to be an indicator of readmission probability (OR 1.03)(CL 0.96, 1.09)(p-value *) when compared to later discharge, > 48 hours (Danielsen, et al., 2000).

A study by Liu (1997) found that after adjusting for birth year, gestational age, maternal race and ethnicity, payer type, maternal complications during pregnancy, sex, and parity, discharging a seemingly healthy infant at 30 hours or less after birth could increase the risk of readmission within the first 28 days by 22%. Another study found that very early discharge increased readmission by 30% compared with later discharge (Danielsen, et al., 2000). Lock & Ray (1999) noted that readmission rates rose from 6.7% to 11.7% after an early discharge program was implemented.

Beebe, Britton, Britton, Fan, and Jepson (1996) commented that the "Appearance of subtle signs of sepsis, congenital heart disease, or other anatomic anomalies may not be present in the first few hours after birth and may not be immediately recognized by parents at home," and another study posits that longer stays can increase the probability of detecting congenital heart anomalies (Kuehl, Loffredo, & Ferencz, 1999). Some hazards of a shortened LOS could be unrecognized jaundice and missed congenital malformations, which could be mitigated with daily home visits (Hellman, et al., 1962). Infants discharged very early were found to have an increased likelihood for readmission from congenital anomalies, jaundice, and dehydration than other infants (Danielsen, et al., 2000). An additional study also found an increase in readmissions for jaundice and dehydration in infants that were discharged earlier (Lee, et al., 1996).

A further study found several factors that were associated with early discharge. Maternal age of 35+, maternal education level less than high school graduation, Medicaid or no insurance, plans to breastfeed, inadequate prenatal care, and midwife attendant at birth were all factors associated with an increased likelihood to be discharged early. Early discharge by region was also studied, and the Northwest and Midwest regions were more likely to experience later discharges than the South, while the West was more likely to experience an early discharge than any other region (Margolis, 1997). In an additional study, self pay and managed care insurance were found to increase the likelihood of early discharge, and the presence of a maternal complication was likely to decrease the likelihood of an early discharge (Danielsen, et al., 2000). Sociodemographic factors that have been previously found to be associated with adverse outcomes have now been found to decrease the likelihood of same day discharge (Danielsen, et al., 2000).

The literature seems to suggest that a very early discharge may increase the risk of readmission due to unrecognized health issues, but an early discharge does not seem to increase the readmission risk. Regardless of literature findings on the matter, the trend of early and very early discharge for seemingly uncomplicated deliveries is likely here to stay. With the current state of the economy, healthcare organizations cannot afford to extend every newborn infant's stay in the hospital. While the practice does appear to be relatively safe for the majority of infants, measures must be taken to identify those infants that could be at risk for adverse outcomes.

2.1.2.2.3.3.7 Breastfeeding at Discharge

The final infant characteristic is the prevalence of breastfeeding at discharge, Martens et al. (2004) found that infants that were not breastfeeding at discharge (OR 1.32)(CL 1.20, 1.44)(p-value <.001) were significantly more likely to be readmitted than those that were. This may be because many infants do not begin breastfeeding until the third day after birth and any difficulty starting the breastfeeding process may require the infant to be readmitted for dehydration or failure to thrive.

2.1.2.2.3.4 Pregnancy Characteristics

2.1.2.2.3.4.1 Prenatal Care (Kotelchuck Index)

The Kotelchuck Index of prenatal care classifies adequacy based on the advised number of prenatal visits compared to the number of visits attended (Utah Department of Health, n.d.). Compared to the reference of adequate prenatal care, neither inadequate (OR 0.95)(CL 0.89, 1.02)(p-value *) or intermediate (OR 0.95)(CL 0.90, 1.01)(p-value *) prenatal care showed an increased incidence of readmission. Adequate plus care (OR 1.15)(CL 1.09, 1.21)(p-value *), however, did (Danielsen, et al., 2000). It is possible that the increased incidence of readmission for the Adequate Plus care group occurs because pre-existing conditions were identified prior to birth that may later require an extended stay or later readmission. Paul, et al. (2006) also looked into the relationship between readmission and the beginning of prenatal care. It was found the starting trimester for prenatal care was significant with a p-value of <.001. Using the first trimester as a reference, never starting (OR 0.25)(CL 0.08, 0.83)(p-value *) or starting prenatal care in the second (OR 0.73)(CL 0.61, 0.87)(p-value *) trimester were associated with decreased risk for readmission. Starting prenatal care in the third trimester (OR 0.73)(CL 0.51, 1.04)(p-value *) was not found to be associated with readmission.

2.1.2.2.3.5 Hospital Characteristics

2.1.2.2.3.5.1 Facility at Birth

Very little research has been done on hospital specific characteristics although several studies have shown that readmission may be related to specific hospital factors. Escobar et al. (2005) found Odds Ratios between their reference of 1.0 and 3.05 for their study of 5 hospitals. and Young, et al. (2013) found 9 hospitals out of 21, ORs between 0.44 and 2.6, that were significantly above or below the mean. Another study has suggested that there may also be a relationship between hospital discharge timing and newborn readmission that may be hospital specific (Johnson, et al., 2002). Discharge decisions, treatment plans, and follow-up care policies are also all typically facility specific characteristics (Escobar et al., 2005). Further studies would need to be conducted to determine if there are specific care or lack of care practices or other factors that could drastically affect newborn readmission rates.

2.1.2.2.4 Studies on Readmission for Jaundice/Hyperbilirubinemia

As jaundice is considered to be the most common cause for preventable readmissions, several studies have explored the relationships between many of the common factors for readmission with infants that were readmitted with jaundice. One study found that the white or Asian race/ethnicity, primiparity, premature rupture of membranes, preterm birth, and breastfeeding during hospitalization were all associated with increased readmission for jaundice rates (Geiger, Petitti, & Yao, 2001). Newman, et al. (2000) determined that the mother's age, Asian mothers, the infant as the mother's first child, a family history of jaundice in newborns, gestational age, male gender, vacuum delivery, and breastfeeding were all associated with an increased risk for readmission in infants with jaundice. Another study by Farhat and Rajab (2011) found that breastfeeding and a LOS of 48 hours or less contributed to increased readmission rates for jaundiced newborns. Danielsen, et al. (2000) also found female gender to be less likely to be readmitted for jaundice.

2.1.2.2.5 Studies on Readmission for Dehydration, Failure to Thrive and Other Feeding Related Issues

Improved promotion for breastfeeding has likely increased its prevalence leading to an increase in inadequate breastfeeding (Change, et al., 2012), which is likely to cause an increase in incidences of dehydration, failure to thrive, and other feeding issues associated with breastfeeding difficulties. One study suggests that rest and lactation instruction provided on the third postpartum day may be beneficial in reducing issues associated with the initiation and success of breastfeeding (Hall, Simon, & Smith, 2000). Tomaskek et al. (2006) found that infants discharged early were more at risk for readmission. Focusing on breastfeeding education before discharge and providing an outlet for new mothers to ask questions could mitigate issues related to breastfeeding. Soskolne (1996) encourages healthcare organizations to teach mothers the early warning signs of dehydration and inadequate feeding and encourage them to seek assistance early for any issues.

2.1.2.2.6 Studies on Readmission for Infections

Several studies have found that breastfeeding provides infants with a protective effect against infection, particularly among disadvantaged populations (Cunningham, Jelliffe, & Patrice Jelliffe, 1991; Feachem & Koblinsky, 1984; Huffman & Combest, 1990; "Nutrition During Lactation", 1991). It has yet to be determined, however, if breastfeeding has a significant health effect on more affluent populations (Bauchner, 1986). Further information on readmissions caused by infections could not be found as it is widely regarded as an unpreventable illness.

2.1.2.2.7 Studies on Readmission for Congenital Anomalies

Some factors that are known to currently affect the likelihood of congenital malformations are genetic factors such as consanguinity of parents or some ethnic specific genetic mutations, socioeconomic and demographic factors including advanced maternal age and insufficient nutrition of the mother during pregnancy associated with lower socioeconomic brackets, environment factors such as an exposure to pesticides, certain medications, alcohol, or tobacco, maternal infections like syphilis and rubella, and maternal nutritional status such as an insufficient intake of folate during pregnancy (WHO | Congenital anomalies, 2016).

2.1.2.2.8 Studies on Readmission for Infectious, Parasitic and Respiratory Illness and Rule Out Sepsis

There is currently no literature available on the factors associated with these illnesses and how they might be mitigated. These types of illnesses are generally considered to be unpreventable and have therefore not been studied in depth. Young, et al. (2013) determined that readmission for sepsis and respiratory distress probably cannot be prevented. Only hyperbilirubinemia is subject to intervention (Farhat & Rajab, 2011).

2.1.2.2.9 Readmission Costs

After the NMHPA was passed, an analysis of the potential impact and costs savings was needed. Although it has been quite some time, the literature remains unclear on what the cost savings of shortened length of stay may actually be. In one study, Maier promised mothers 48 hour stays. If insurance wouldn't pay for the 2nd day, the hospital will pay the approximately $300 cost (Maier, 1995). Tai-Seale, Rodwin, and Wedig (1999) estimated that implementing a shortened length of stay saves about $280 per patient but then states that actual cost savings may be even smaller. Liu and Norton (2004) posits that increasing length of stay for every infant in order to save one life would cost approximately $1.79 million. Regardless of whether savings are truly realized when readmissions are taken into account or not, shortened length of stays will probably remain.

It has been estimated that up to 86% of all readmissions occur within the first six days following delivery (Johnson, et al., 2002). Young, et al. (2013) found the mean readmission LOS was 68 ± 77 hours with a range from 12 to 345 hours. A median cost per readmission of $6,737 was found by Evans, Garthwaite, and Wei (2008), meanwhile, Young, et al. estimated the mean cost per readmission was $4,548 ± $8,893 with a range between $382 and $31,784.

2.1.2.3 Neonatal Mortality

According to the World Health Organization [WHO], almost 45% of all deaths for children under 5 occur within the first 28 days of life (WHO | Newborns: reducing mortality, n.d.). 75% of those deaths occur within the first week of life, and up to two-thirds of neonatal deaths can be prevented if appropriate health measures are provided at birth and through the first week (WHO | Newborns: reducing mortality, n.d.). Although these statistics include developing countries where adequate maternal and neonatal healthcare may not be readily available, the literature indicates similar occurrences.

2.1.2.3.1 Mortality Causes

The National Vital Statistics Report for 2013 found the leading causes of infant mortality to be congenital malformations, deformations, and chromosomal anomalies, 20%, disorders relating to short gestation and low birth weight, 18%, newborns affected by maternal complications, 7%, Sudden Infant Death Syndrome [SIDS], 7%, and accidents or unintentional injuries, 5% (Mathews, MacDorman & Thoma, 2015). These five causes accounted for 57% of all infant deaths. MacDorman, Declercq, Menacker, and Malloy (2006) determined that the five leading causes of death for their study were congenital malformations, deformations, and chromosomal anomalies, 54.2%, SIDS, 5.3%, intrauterine hypoxia and birth asphyxia, 4.4%, diseases of the circulatory system, 3.7%, bacterial sepsis of newborn, 3.1%, and all other causes, 29.3% (MacDorman, et al., 2006). Another study found that their population mortality was caused by SIDS, 66.5%, heart related conditions, 9%, and 5.2% were caused by infections. All of the remaining deaths were caused by accidents and injuries, nervous system conditions, respiratory conditions, gastrointestinal conditions, other conditions, and unknown causes (Malkin, 2000).

2.1.2.3.2 Mortality Factors

The neonatal mortality rate for the U.S. was 5.96 deaths per 1,000 live births in 2013. Infants that were born preterm or late preterm had a 63% higher incidence of mortality (Mathews, et al., 2015). Malkin (2000) found that infants that were discharged earlier were more likely to die of heart related illness, infections, and other causes within the first year after birth than those infants that were discharged later. Another study by MacDorman, et al. (2006) determined that neonatal mortality could be linked to delivery method and parity. They determined that primiparous mothers had a 56% higher incident of mortality for those having cesarean deliveries than for vaginal (MacDorman, et al., 2006). They also found multiparous mothers to have almost twice the incidence of mortality for cesarean section compared to vaginally. Male gender had a 21% higher occurrence of mortality than their female counterparts and low birth weight mortality was almost 25 times higher compared with their counterparts weighing 2500 grams or more (Mathews, et al., 2015). Further mortality data is limited as incidence of mortality in most study populations is well below the level of significance.

2.1.2.4 Attempted Interventions

Yanover, et al. (1976) attempted to reduce newborn LOS to free up bed space. To ensure that the newborn and mother were adequately cared for, all discharged infants received daily home visits. The cost of the daily home visits was found to be equivalent to the cost of care in a hospital (Yanover, et al., 1976). Several studies in the literature focused on reducing readmissions for jaundice. After implementing universal bilirubin screening, one study found rehospitalization for hyperbilirubinemia dropped from 5.5% to 4.3% per 1000 (Eggert, 2006). Another study implemented an intervention that included improved risk screening, bilirubin evaluation, a priority lactation consultant for at risk infants, a post-discharge lactation clinic, home health follow-ups and phototherapy. With these interventions a 75% reduction in readmissions was realized (Allen, Strohecker, & Maurer, 2012). Barilla (2008) attempted an intervention for increased psychosocial support that saved $513,540 in estimated readmission costs but was not cost effective as it required an estimated $1,183,600 to implement.

Although several types of interventions have been attempted, many of them do not indicate intervention costs. Of those that do note specific cost, none of those that have been analyzed in this literature review were cost effective. Intervention methods for newborn infants seem to have consistently focused on the prevention of jaundice or breastfeeding education. All of the studies that have been analyzed in this review focus only on healthy newborn infants, and none of these studies attempt to address the same issues in all discharged infant populations. Infant and newborn care practices and follow-up routines are particularly resistant to change (Paul, et al., 2006), so intervening in hospital policy or routines can be quite difficult. Healthcare staff are also typically quite busy and may be resistant to learning new methods that differ from those that have been around for years.

2.2 Research Methods

The background information for several research methods is provided in this section. This information should answer research questions and facilitate the development of the research design.

2.2.1 Health Systems Engineering

Health systems engineering or health engineering is a discipline that focuses on the use of engineering design and analysis principles in the field of healthcare. Individuals that work in this field may be from engineering, science, or mathematical backgrounds, among others. Health systems engineering may often be referred to as Health Care Systems Engineering [HCSE], and can cross over into such disciplines as biomedical engineering, industrial engineering, operations management, medicine, pharmacy, dentistry, nursing, and many others. Several other fields that may participate in HCSE are public health, information technology, management studies, and regulatory law (Wikipedia | Health systems engineering, n.d.).

2.2.1.1 Industrial Engineering in Health Systems Engineering

Industrial engineering [IE] has a wide variety of applications to health systems engineering. HCSE personnel may employ a wide variety of IE principles in their daily work. Optimization, decision analysis, human engineering or human factors engineering, ergonomics, quality control or quality engineering, value engineering, and the general mentality of continuous improvement are all industrial engineering principles that are prevalent in the health systems engineering career field.

2.2.2 Ishikawa Diagramming

The Ishikawa diagram or "fishbone" diagram is a root cause analysis structure that allows for pictorial representation and identification of the underlying factors associated with an adverse event or outcome (QAPI, n.d.). This type of diagram helps with brainstorming to identify the potential causes of a problem and is particularly useful as it can divide ideas into categories. In an Ishikawa diagram, the main problem being analyzed or addressed sits at the "head" and the smaller "bones" are the various underlying causes (Program Manager Toolkit, 2017). In order to determine the root cause of an issue, the five "whys" technique is often used in conjunction with the Ishikawa diagram until such a time as the "why" can no longer be identified down a further level (QAPI, n.d.).

2.2.3 Simulation

According to White and Ingalls (2009), simulation is experimentation with a model. Models are typically only employed to the scope and level required to adequately depict a system object and are used when physical investigation of a system is impossible or impractical. Investigators can perform "what if" analyses with the assistance of simulation modeling and are able to explore scenarios and risks in order to evaluate a system without having to invest in the actual system changes (White and Ingalls, 2009).

There are currently three methods of simulation modeling, continuous, discrete-event, and agent-based modeling. Continuous event modeling is used when there are variables that change constantly (Law, 2015). Discrete event modeling is suitable for modeling a more flowchart like process that contains entities, resources, and processes (Banks, 2007), and agent based models contain autonomous decision-making entities referred to as agents (Helbing, 2014).

2.2.3.1 Application of Simulation in Health Systems Engineering

While simulation in healthcare is not uncommon, there are relatively few instances of simulation and its application in newborn healthcare available in the literature. One study performed an analysis of emergency room wait time issues via computer simulation and determined that the availability of physicians and the time spent educating medical residents both had a significant impact on wait time (Blake, Carter & Richardson, 1996). Blake et al. (1996) then designed an intervention where minor injury patients were fast-tracked and an increased number of physician hours were added to the emergency room. Another study by Khurma, Baciouiu, and Pasek (2008) used simulation modeling to compare the use of a combination of lean tools on current and future state models to determine solution feasibilities.

Additionally, Miller, Ferrin, and Szymanski (2003) tested design ideas for a planned facility along with several emergency department simulations to aid Six Sigma project leaders with process improvement initiatives, while Kelly (2001) simulated policy interventions using the removal of newborn factors from multivariate regressions models to determine the impact of targetable factors in newborn care.

2.2.4 Interventions in Newborn Health Care

In attempting any intervention in the healthcare system and particularly in newborn healthcare where the population is extremely vulnerable, it is important to determine the most appropriate audience for any intervention strategy. An intervention strategy will usually include the transfer of information that is given at the level in which the recipient can easily understand and retain. Furthermore, when designing an intervention, it is important to choose the correct format in order to connect with the recipient as different formats can drastically effect the recipient's retention. Other questions that must be answered when designing an intervention include the channel or resource through which the intervention will be attempted and what point in the workflow will the intervention target.

This paper focuses on the development of a framework and analysis for intervention in newborn healthcare. Some questions to consider when using the components of this dissertation for interventions follow the use of Osheroff's five "rights".

- the right information

The main question in any education based healthcare intervention is what information needs to be transmitted? Determining the topics that will most effect readmission, severity, and mortality rates will determine the topics that should be addressed. After these topics are determined, educational material should be crafted by each facility that is most in line with the facility's goals and practices.

- to the right person

One proposed target for this information could be the infant's caregiver, usually the mother, as after discharge, the caregiver will begin making all decisions in regards to the infant's health. These decisions will include daily care such as position of sleep and timing of feedings but will also extend to deciding when and if the newborn will return to receive follow-up care appointments or be readmitted for possible issues. Therefore, as the main decision maker for the newborn infant's health, an intervention may be more productive when issued directly to the infant's primary caregiver. For infants in a multiple parent household, some intervention types could potentially be transmitted to two or more caregivers with the same amount of cost and effort.

- in the right intervention format

How information is presented will impact how it is received by the recipient. Information will need to be sent in easy to understand and manageable pieces. If the infant's parents are not capable of understanding the information, then its intended purpose will not be received. Some statistics indicate that the average reading level of the U.S. is approximately the 7th to 8th grade reading level, which is consistent with many guidelines for medication (Wikipedia | Literacy in the United States, n.d.); therefore, any information presented to the infant's care-givers would need to be at this level or lower. The wording of the educational material may also have an impact on retaining and understanding the given message.

Additionally, the information must be presented in small enough pieces so that the information is thoroughly reviewed and understood. If the presented information is too long the caregiver may not read all the way through. If it is too short, the message may not be communicated effectively.

- through the right channel

The channel in which information is presented to the caregiver will impact the timing of its receipt, the ease of access, the likelihood that the information will be reviewed, and how it is viewed.

- at the right time in workflow

Information must be delivered at an appropriate time by the practitioner, or the patient is less likely to remember it when it is needed, or it may be needed earlier than it is delivered.

When designing an intervention, it is important to consider each of these areas carefully. Combining an intervention with the proposed tools would allow for an easier analysis of results and the ability to 'test' scenarios before enacting them. Case studies of different intervention types would allow the practitioner to have data related to their own system, which would produce even more accurate results.

CHAPTER 3
RESEARCH DESIGN

This chapter will provide an overview of the research design that will be employed in this dissertation in order to answer the research questions. This overview will include the formulation of the architecture for each subsection of the research and how it applies to the final problem domain.

3.1 Literature Review

This area contains an extensive literature review of healthcare systems engineering, infant readmission characteristics, and infant mortality characteristics in order to understand what literature currently exists. Additional literature searches were performed to keep material up to date. The literature review can be found in Chapter 2.

3.2 Literature Analysis

After analyzing the current body of literature, opportunities for further research were identified. This analysis was used to identify the domain of the research.

3.3 Healthcare Systems Engineering Ishikawa Diagram Development

An analysis of the presented research was conducted to determine the major causes for readmission across all studies as well as some of the reasons why those readmissions might occur. Readmission was then further divided into subsections of factors that could build a model of factors effecting readmission. An Ishikawa diagram was created for Overall Readmission Causes, Figure 4.1.1.1, Increased Readmission Rates in the Literature, Figures 4.1.1.2 and 4.1.1.3, and Decreased Readmission Rates in the Literature, Figure 4.1.1.4. Each bone of the diagram was taken from one of the recorded studies. Only those factors which were found to be significant, either via p-values or confidence limits, were included.

Factors that were found to be conflicting in nature were divided into three categories. Those factors which were conflicting but appeared in multiple sources where the majority reached a consensus were recorded under that diagram. For example, male gender was found to be a significant indicator of readmission in several studies; however, one study found that female gender was instead the more likely to indicate readmission. As several studies agreed on the nature of the male gender relationship with readmission and only one disagreed, male gender was recorded under the diagram associated with increased readmission rates.

In the cases where a factor was found to be significant but the number who indicated each relationship, increased or decreased rates, was equal, such as in the case of vaginal versus cesarean delivery, the factor was not included in either diagram. Some factors such as LOS and discharge timing may have disagreed in some categories, but other categories may have agreed. In this case, the categories in which an agreement was reached were included in the diagrams.

3.4 Healthcare Systems Engineering Simulation Model Development

The purpose of the simulation model is to design a working model of the broad hospital or multi-hospital system such as it exists from the literature. The working model may then be used to cost compare different intervention methods with a focus on determining the cost effectiveness of a given solution compared to other methods. This model will attempt to reduce not only preventable readmissions and mortality but will also allow the user to manipulate and determine where the greatest cost affects might be occurring.

Using the information from the literature analysis, a simulation architecture was developed to model readmission and mortality for the system. Attributes were assigned to each infant at the start of the model. All attributes were assigned based on the combined categories derived via forest plots to combine multiple studies into a set of comparable categories. This was done using odds and risk ratios. Although odds ratios do not actually depict the risk of an outcome but rather probabilistic odds, when the effected percent of a population is less than 10%, as is the case for readmission and mortality, the odds ratio may be used as a reasonable estimation of the risk ratio (Viera, 2008). Using the assigned attributes and their corresponding odds/risk ratios, categories were developed to allow for future work with this simulation. These categories combined with data on the interaction between factors can allow for a more complex system model that would be able to track subtle occurrences related to readmission, illness, and intervention manipulations.

3.5 Validation of Simulation Architecture

After the development of the framework of the simulation model, the next task was to validate the framework. The advisor for this project approved a first stage validation of the simulation architecture to ensure that the components were valid and a logical representation of the system. Based upon recommendations, the system was updated until a final model was obtained. Once the final architecture was obtained, the data requirements were identified and compiled.

3.6 Identification of Simulation Data Requirements

After the validation of the simulation architecture, the data requirements of the simulator were identified and compiled. Data that had not already been obtained was found from other sources or through additional research methods such as surveys. The majority of the data for this simulation model was obtained from the National Vital Statistics Report 2014 by Hamilton, et al (n.d.). Any additional data needed was estimated as several areas did not have data available.

3.7 Data Collection

Using the identified data requirements, data for each component was collected. Some quantitative data was found for various factors in the current literature or through publically accessible healthcare databases including such information as is offered by agencies such as the CDC's National Vital Statistics Reports (n.d.). Data for each component was collected and recorded.

3.8 Statistical Analysis of Collected Data

In this step, the existing data was analyzed. Any data that could not be directly entered into the model was statistically analyzed and steps were taken to address issues. Factors and their relationships were examined and required distributions were assigned for all necessary characteristics. At this point, all remaining analyses were completed and data was entered into the model.

3.9 Enter Analyzed Data into Simulator

At this point, the simulation model was populated with the analyzed data. The model was observed as it was run in order to identify any initial problems. The model is expected to output reasonable results. If any problems occurred in this phase, they were found and addressed.

3.10 Development of C Based Program of Newborn and Group Characteristics

In addition to the simulation, a C based program was developed that would allow a practitioner or researcher to enter the characteristics that have been identified as an area of interest of study. The practitioner could then add information on these factors for a number of infants before calculating odds ratios for each readmission factor and confidence intervals of the corresponding odds ratios. The program was also developed to allow the system to print out those characteristics held by an individual infant that may contribute to adverse outcomes to allow for easy identification of at risk infants and to provide information on which areas practitioners may wish to target to decrease the risk for readmission. Furthermore, the program was also developed to allow for practitioners to enter a specific characteristic to receive pre-developed information that could be used for a specific subset of infant characteristics enabling practitioners to quickly pull together the most relevant information for an infant or infant populations' specific characteristics.

CHAPTER 4
RESEARCH RESULTS

This chapter contains the results of the research. It is organized to provide the results for each section discussed in Chapter 3. The research results include the Ishikawa diagrams, forest plots for developing simulation categories, the simulation architecture, and the C program architecture.

4.1 Ishikawa Diagrams

4.1.1 Ishikawa Diagram Results

In an Ishikawa diagram, sometimes called a fishbone diagram, the main line considered as the spine of the fish is the area of interest. Each 'bone' that branches from that line is considered to be something that contributes to that area. Each smaller bone off of each larger bone contributes in some way to that sub-area. An Ishikawa diagram is used to determine the "root causes" for the problem listed at the far right of the diagram or the "head" of the fish. As an example, when looking at readmission, one of the root causes of readmission is Jaundice. Genetic factors and insufficient screening before discharge are two examples of things that may contribute to readmissions for jaundice. Performing these root cause analyses allows for the true cause of an issue to be found and addressed.

After an analysis of the presented research was conducted to determine the major causes for readmission across all studies as well as some of the reasons why those readmissions might occur, Ishikawa diagrams were created for Overall Readmission Causes, Figure 4.1.1.1, Increased Readmission Rates in the Literature, Figures 4.1.1.2 and 4.1.1.3, and Decreased Readmission Rates in the Literature, Figure 4.1.1.4. Each bone of the diagram was taken from one of the recorded studies. Only those factors which were found to be significant, either via p-values or confidence limits, were included.

These diagrams were created to pinpoint those areas which might be most useful in determining and understanding the causes and relations between specific characteristics and infant readmission.

Those branches of the diagrams which were determined to be most relevant were then further investigated to produce categories which could be made comparable across multiple studies.

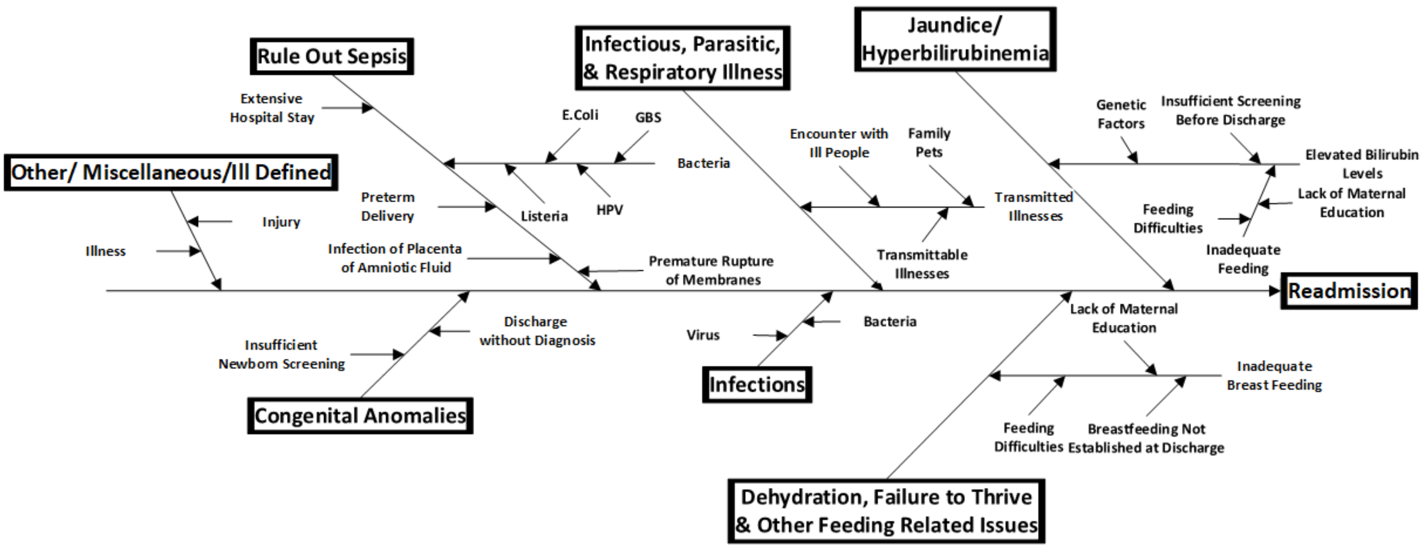

Figure 4.1.1.1 Ishikawa Diagram for Overall Readmission Causes from the Literature

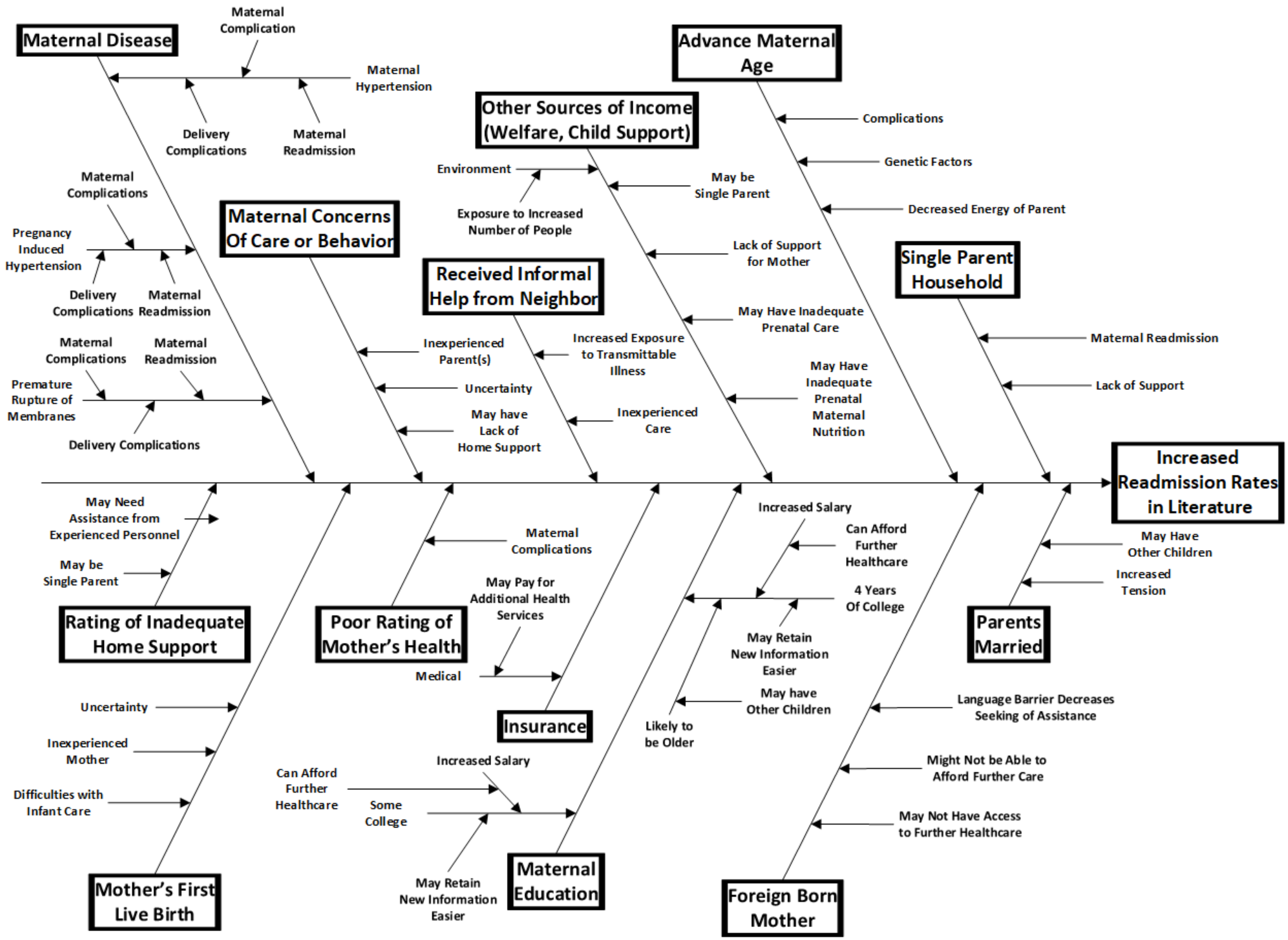

Figure 4.1.1.2 Ishikawa Diagram of the Factors Related to Increased Readmission Rates in the Literature Part A

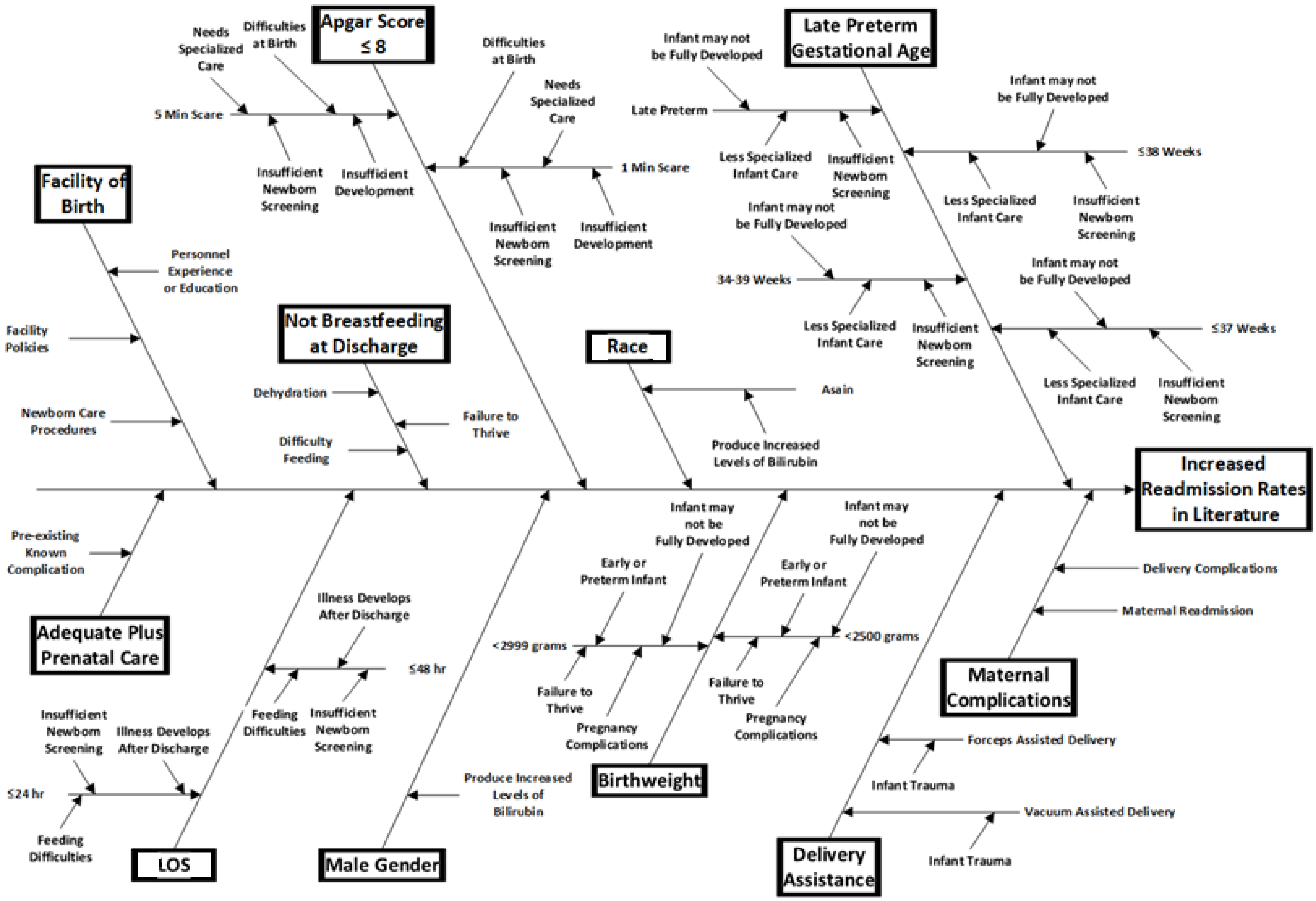

Figure 4.1.1.3: Ishikawa Diagram of the Factors Related to Increased Readmission Rates in the Literature Part B

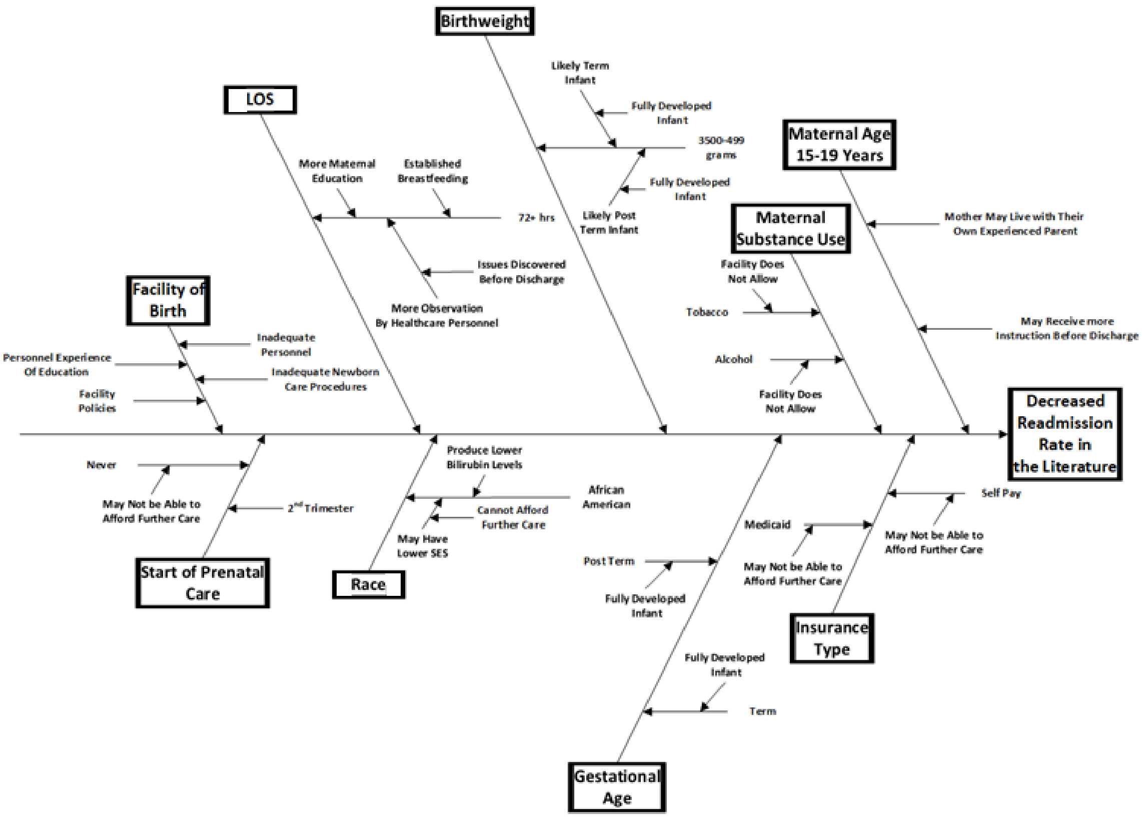

Figure 4.1.1.4: Ishikawa Diagram of the Factors Related to Decreased Readmission Rates in the Literature

4.2 Creation of Comparable Categories and Forest Plots

4.2.1 Creation of Comparable Categories

In order to use the available literature to create comparable categories, many of the studies required the combination of a large number of categories into a smaller number of categories. When one study might have four or five sub-categories and another might have only two, the larger number of categories were combined into appropriate groups containing all those subgroups which would be present in a study with fewer but larger subgroups. One such example might be in maternal age. While one study might break maternal age down into < 18 years, 18-35 years, and 35+ years, another study might use increments of 5 years to have <18 years, 18-20 years, 20-25 years, 25-30 years, 30-35 years, 35+ years. In the latter case, the average of those categories that fit in a similar age group was taken. Ex. Average of 18-20 years, 20-25 years, 25-30 years, and 30-35 years would be comparable to 18-35 years in the study mentioned first.

4.2.2 Forest Plots

After comparable categories were created, forest plots of different factors were generated based on the method provided in Akobeng's study on meta-analysis (2005). Forest plots allow for meta-analysis across multiple studies. They show how comparable the data collected between multiple studies is and allow the user to determine whether the studied factors appear similar or vastly different among the literature. For each forest plot below, every study listed has been given a weight, which is represented by the amount of the data set taken up by the blue squares. Larger squares indicates a larger weight was given to that specific study. The red dotted line and diamond indicate the weighted average for the overall study results, and the red odds ratio and confidence limits are the numerical weighted results of each meta-analysis. Finally, the grey lines to either side of the blue squares indicate an individual study's confidence limits.

In Figure 4.2.2.1, the forest plot of the household Parity/Marital Status is shown. In this figure, there are three studies analyzed. The original odds ratios or, in cases where multiple categories were reduced into a single category, the average odds ratios for each study are indicated to the right of the chart. Corresponding confidence intervals are also indicated for each study. To the right of this data, the weight given to each study is also indicated. Weights were given to each study based upon the definition of newborn, i.e. how each study defined newborn with the highest weights given to those studies that used 0-28 days to define a newborn infant, the methods of the study, and the number of infants in each study's data set. Each category was assigned a maximum of ten weighted points and a minimum of 1 weighted point. Then each study was assigned a number of points based upon its comparison with the category ideal. For example, if the study defined newborn as an infant from 0-28 days, the study would be awarded a full 10 points. If it assigned a definition of newborn as 0-10 days, it only received 2 points. The weighted average of these numbers were then calculated to produce a final 'factor level' odds ratio, the odds or likelihood that an event will occur, and confidence limits. These numbers appear in red below the individual study information. An example of the calculations for these weighted average odds ratios and confidence limits is shown below for the first figure. The same method is used for all remaining forest plots.

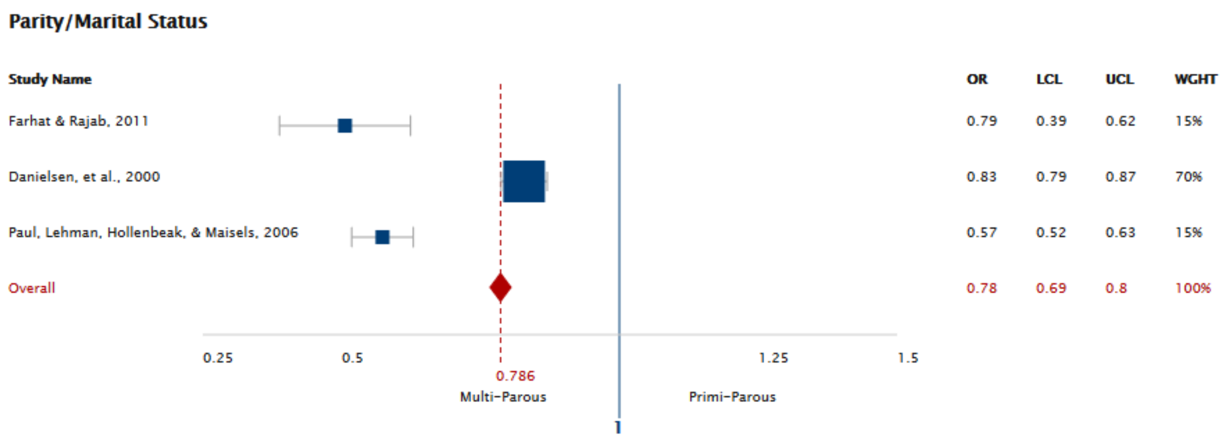

Figure 4.2.2.1: Forest Plot of Parity/Marital Status

$$Overall\ Odds\ Ratio = 0.15 * 0.79\ (Farhat\ \&\ Rajab, 2011) + 0.70 * 0.83\ (Danielsen, et\ al., 2000) + 0.15 * 0.57\ (Paul, et\ al., 2006) = 0.78$$

$$Overall\ Lower\ Confidence\ Limit = 0.15 * 0.39\ (Farhat\ \&\ Rajab, 2011) + 0.70 * 0.79\ (Danielsen, et\ al., 2000) + 0.15 * 0.52\ (Paul, et\ al., 2006) = 0.69$$

$$Overall\ Upper\ Confidence\ Limit = 0.15 * 0.62\ (Farhat\ \&\ Rajab, 2011) + 0.70 * 0.87\ (Danielsen, et\ al., 2000) + 0.15 * 0.63\ (Paul, et\ al., 2006) = 0.8$$

While two of the studies appear to have similar odds ratio and confidence interval results, the highest weighted study found results that were quite a bit different. Overall, the three studies appeared to agree that multi-parous households were likely to see a reduction in readmissions compared to primi-parous households.

In the next three forest plots, maternal age is analyzed. In Figure 4.2.2.2, maternal age of less than 18 years produced differing results across all three studies with the highest weighted study appearing in the middle compared to the remaining two studies that carried larger confidence limits on either side of the weighted results.

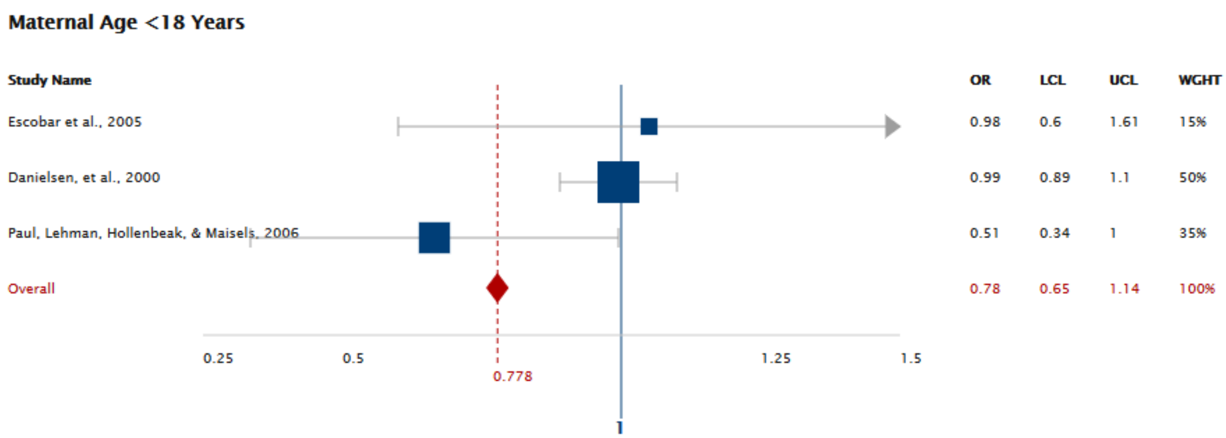

Figure 4.2.2.2: Forest Plot of Maternal Age <18 Years

In Figure 4.2.2.3, the three studies analyzed contained moderately similar results with a great deal of overlap between them. Although, the study by Paul et al. did have a very large confidence interval comparably.

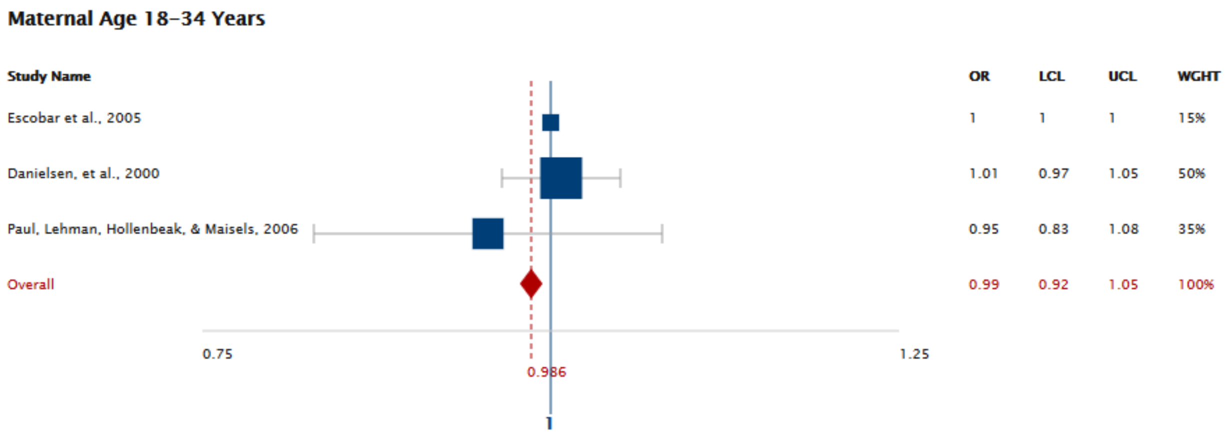

Figure 4.2.2.3: Forest Plot of Maternal Age 18 - 34 Years

In the next forest plot, Figure 4.2.2.4, maternal age of 35+ years also seemed to contain wider confidence intervals among two of the studies, but there was still a considerable amount of similarity between the three.

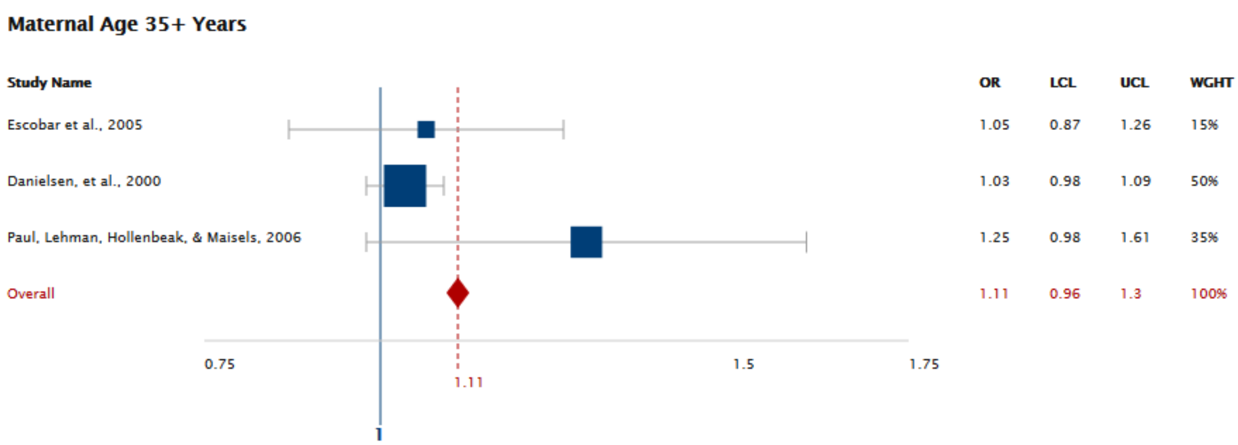

Figure 4.2.2.4: Forest Plot of Maternal Age 35+ Years

Overall, the results for maternal age were generally similar. From the results, however, there is no conclusive evidence to determine how maternal age relates to readmission as all weighted confidence intervals cross the 1.0 threshold.

In the next forest plot, maternal education has been analyzed. As can be seen in Figure 4.2.2.5, maternal education less than high school was not found to be significantly related to either increased or decreased readmission between studies. Whereas, maternal education high school + was found to be associated with an increased risk for readmission, however, these results would require further inquiry as the data set is still relatively small.

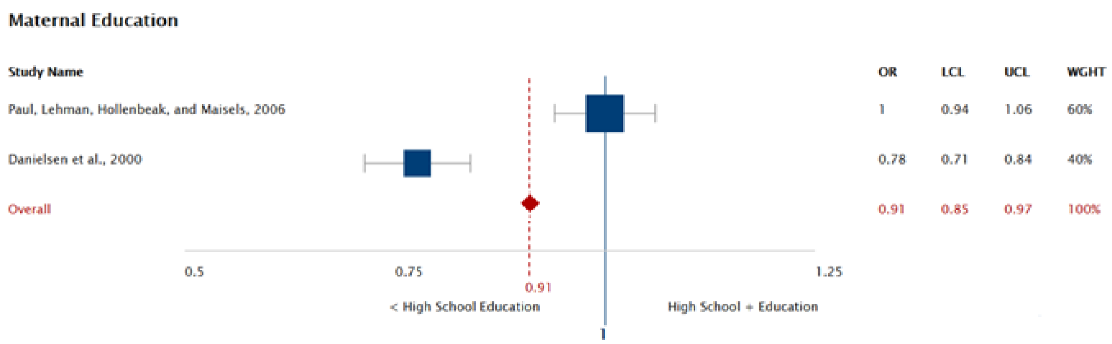

Figure 4.2.2.5: Forest Plot of Maternal Education

In Figure 4.2.2.6, no significant association was found between private versus other insurance types towards readmission.

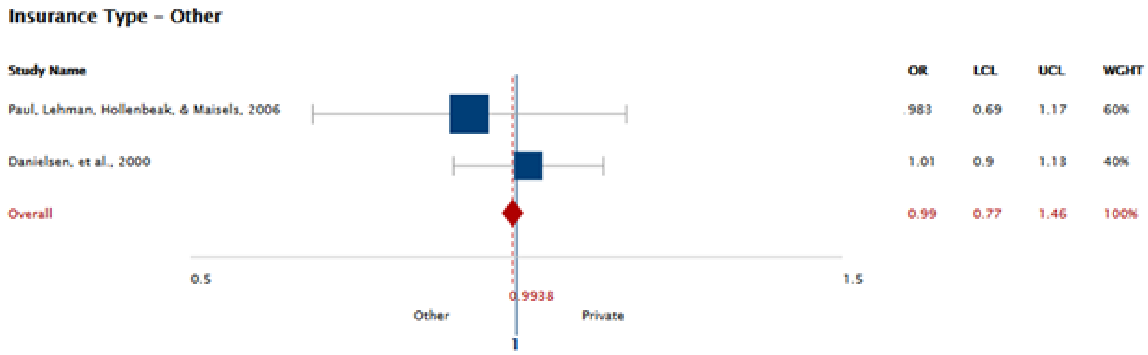

Figure 4.2.2.6: Forest Plot of Insurance Type - Other

The presence of maternal complications was found to be significantly related to readmission in newborns in all listed studies as shown in Figure 4.2.2.7. Although all studies found a relationship, the difference in confidence limits between studies was relatively diverse, and the study by Danielsen, et al. (2000) found values much lower than the other listed studies for both odds ratios and confidence limits.

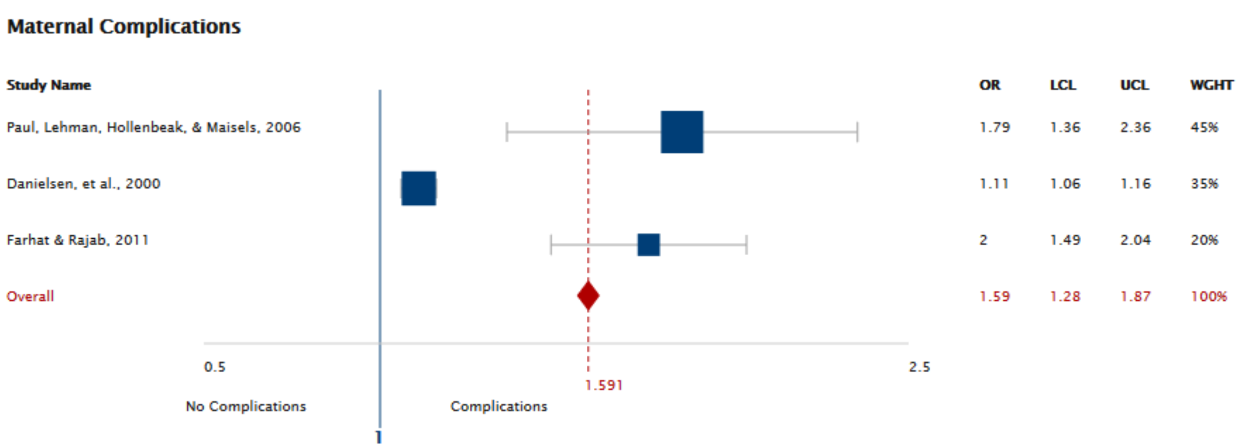

Figure 4.2.2.7: Forest Plot of Maternal Complications

Although the meta-analysis of the next factor, Cesarean Section Delivery, Figure 4.2.2.8, shows a significant effect against readmission for cesarean deliveries, the study by Martens, et al. (2004) actually found the opposite to be true. The weighted odds ratio, however, appears to indicate that there is likely to be some significant relationship between reduced readmission for cesarean deliveries versus those infants delivered vaginally.

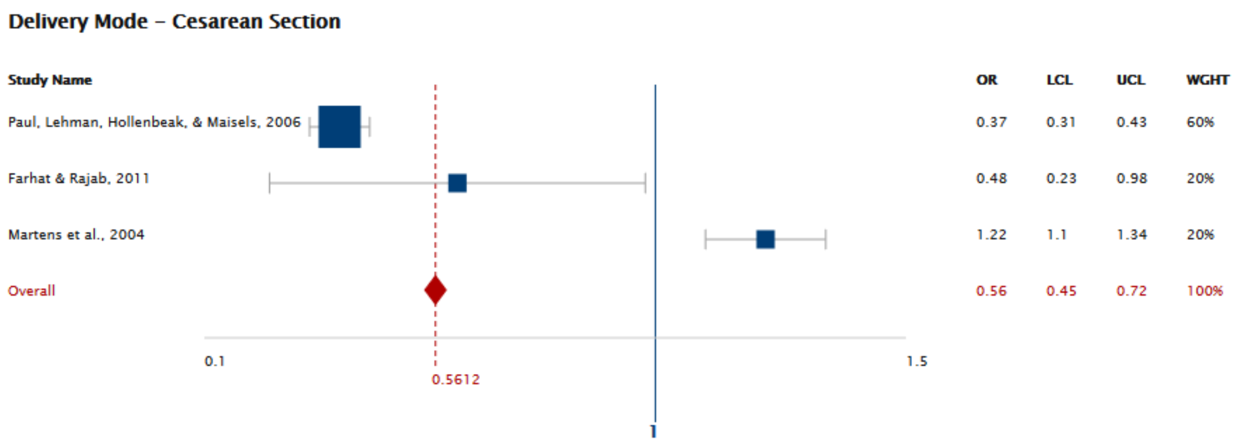

Figure 4.2.2.8: Forest Plot of Delivery Mode - Cesarean Section

The next figure, 4.2.2.9, both show the results of a meta-analysis on gestational age. For a gestational age < 37 weeks, all indicated studies found an increased likelihood for readmission. Confidence limits were vastly different between studies with some being exceedingly large and others quite small. Overall, the weighted odds ratio indicated that readmission was more than twice as likely for those infants that were less than 37 weeks gestational age.

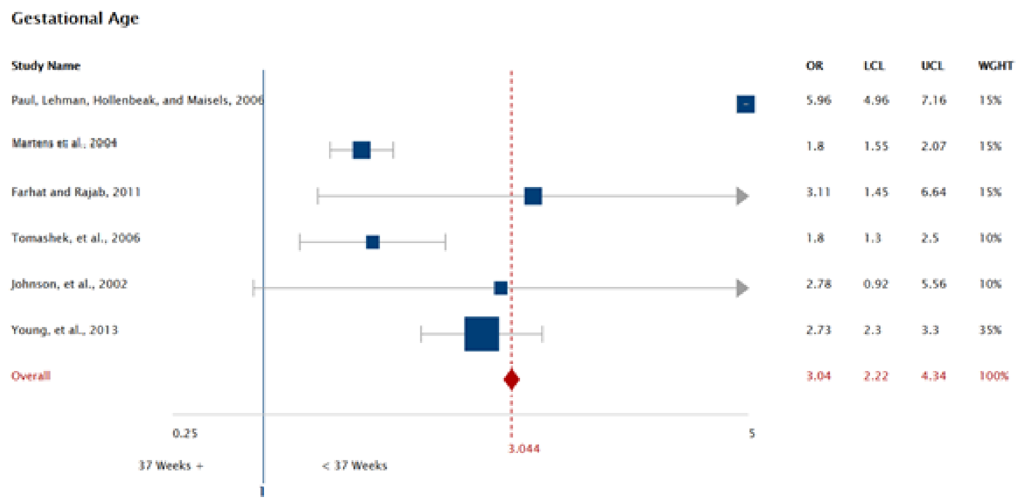

Figure 4.2.2.9: Forest Plot of Gestational Age

In Figure 4.2.2.10, birth weight of <2500 grams was found to be significantly associated with an increased odds for readmission. Although one recorded study did have relatively large confidence limits, there was a considerable amount of overlap in the data sets indicating similarity between studies.

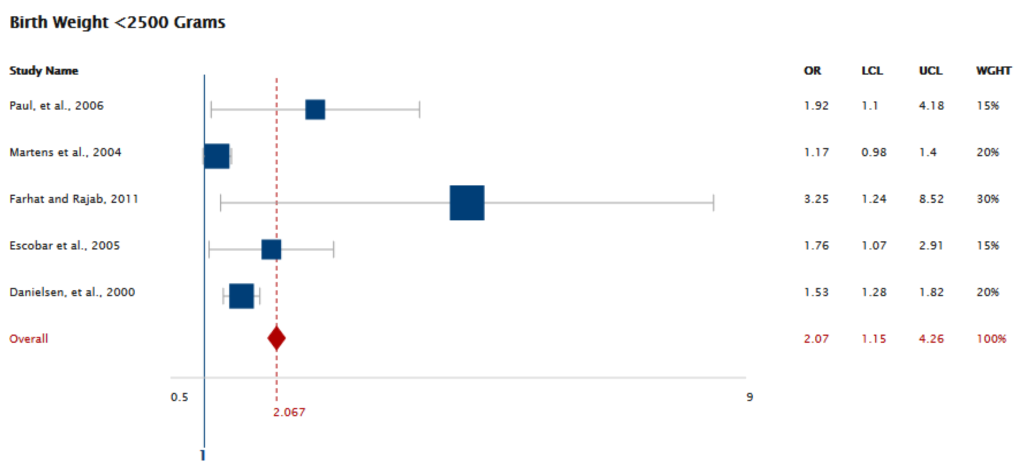

Figure 4.2.2.10: Forest Plot of Birth Weight

Although no significant association was found between gender via the results of the meta-analysis, Figure 4.2.2.11, this is likely due to the widespread confidence intervals in some studies, and the higher weights attributed to those studies that found apposing results. Further investigation would be needed in this area to determine what, if any, association exists.

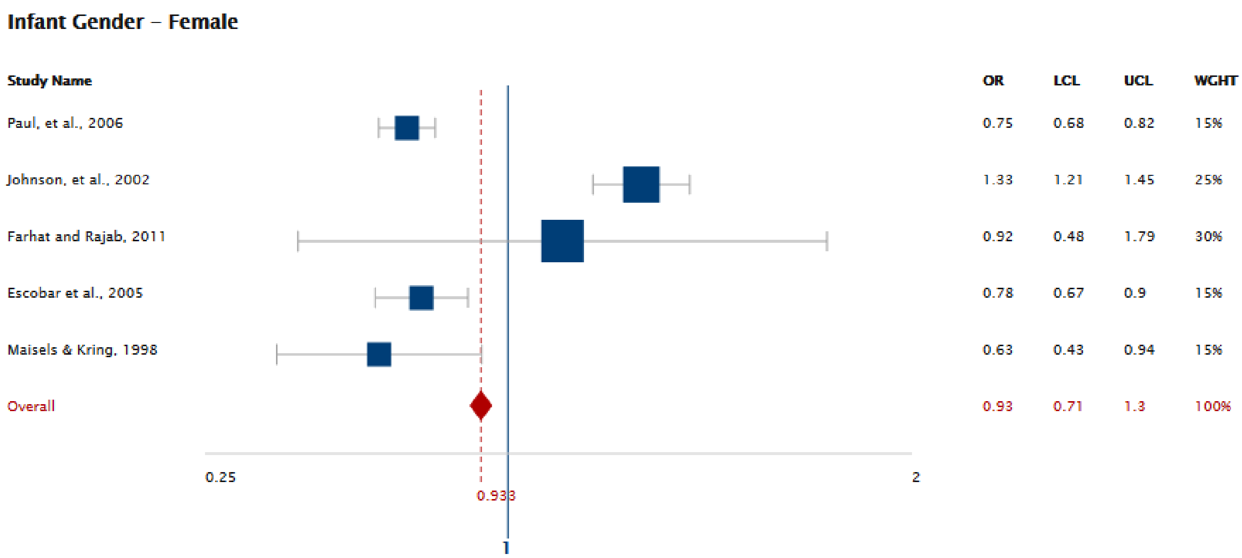

Figure 4.2.2.11: Forest Plot of Infant Gender - Female

All three studies from the literature on infant gender found similar results in Figure 4.2.2.12 with a decreased association between African American race and infant readmission. Similar confidence limits and odds ratios were also present in all study lending further validity to the results.

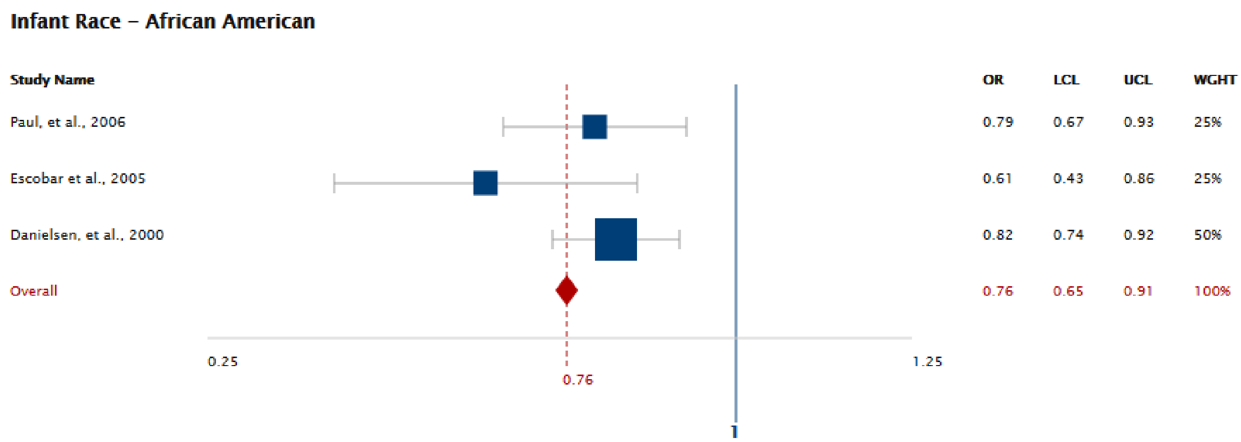

Figure 4.2.2.12: Forest Plot of Infant Race - African American

Opposing the results in the previous figure, Figure 4.2.2.13, found the Asian race to be associated with increased odds for readmission. This meta-analysis also found similar odds ratios and confidence intervals among its data set.

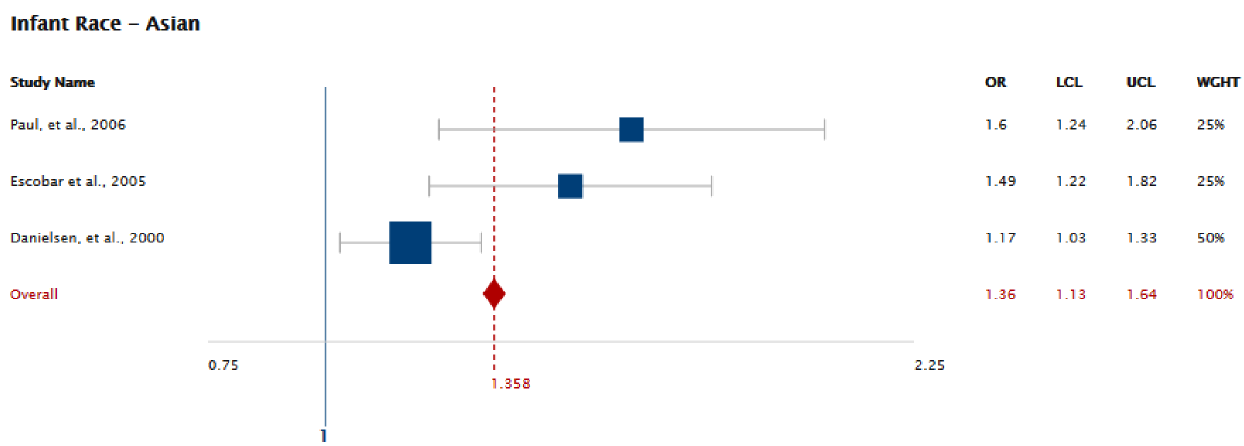

Figure 4.2.2.13: Forest Plot of Infant Race - Asian

As can be seen in Figure 4.2.2.14, Hispanic race was not found to be associated with either an increased or decreased risk for readmission. There were only two studies in this figure, however, so further study could yield more interesting results.

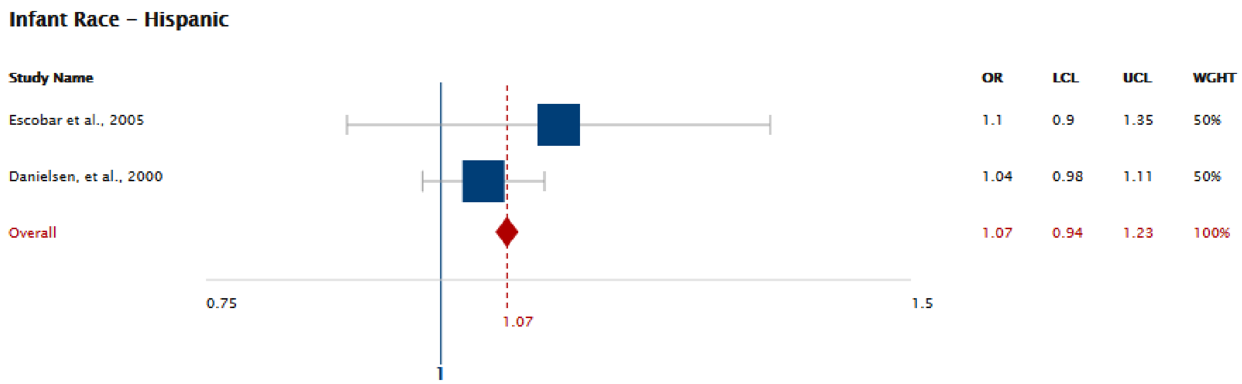

Figure 4.2.2.14: Forest Plot of Infant Race - Hispanic

The final forest plot shown, Figure 4.2.2.15, depicts infant length of stay < 48 hours. An early to very early discharge, 48 hours or less, was found to be significantly associated with risk for readmission. Some concern with this meta-analysis is the significant difference between Farhat and Rajab's (2011) odds ratio and confidence limits compared to the remaining studies.

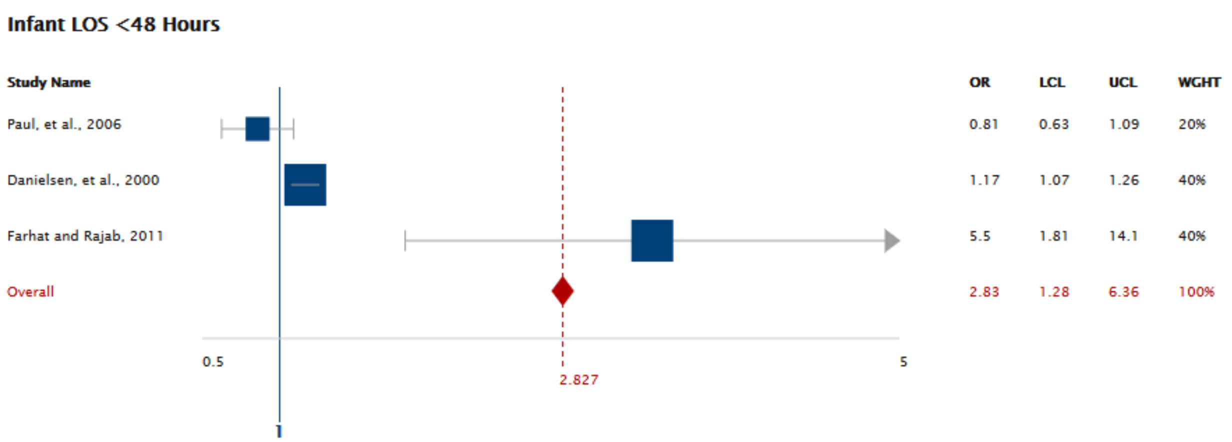

Figure 4.2.2.15: Forest Plot of Infant LOS < 48 Hours

Overall, forest plots allow for the pictorial representation of large amounts of related statistical data. This allows the user to quickly determine what similarity might be found between different studies and allows for quick interpretation of overall results. Data from this section can be used in future work to pair odds ratios with simulation modeling to simulate the system to an even more accurate level than the current model and data can handle.

4.3 Simulation Modeling

4.3.1 Current System

The purpose of this simulation model is to allow the user to estimate the effects of specific changes in a system without having to make changes to the real system. Questioning the likely outcome of a change in a simulation model is less time consuming, less costly, and has less likelihood for negative, life-threatening affects than simply trying out these ideas in a hospital setting with no idea of how each change might affect the overall system. Through the use of ‘what if’ analyses, the user can determine what areas to target for intervention to provide the most useful and cost effective solutions while minimizing the risk for adverse outcomes. This system would ideally be used by someone with a passing knowledge of process improvement such as a lean or six sigma team but could also be used by an intervention creation team with a basic understanding of the concept of simulation and intervention testing.

The simulation model for this dissertation is a representation of a broad readmission and mortality system containing factors from the literature that allows for prediction and ‘what if’ analyses. The model begins by calling each infant into the system and assigning a set of ‘attributes’ to the infant. These attributes can be seen in Figure 4.3.1.1 and 4.3.1.2 below and include maternal marital status, household parity, maternal age, maternal education, birthplace of mother, insurance type, income type, mother’s rating of support, maternal disease, delivery mode, medical assistance at delivery, gestational age, birth weight, APGAR scoring, gender, race, length of stay, breastfeeding at discharge, prenatal care, and facility of birth. Each attribute is assigned based upon a random number generated between 0.0 and 1.0. Each factor category is assigned a range within this range that is equal to the total probability of that specific factor occurring. If the random value generated falls within a factor value’s range, that factor value is then assigned to that attribute. This is repeated for all 20 factors listed with each factor having between 2 and 4 assignable values. In those cases where data existed to define the probabilities of a specific factor value occurring, the National Vital Statistics Report (n.d.) was used. In all cases where this data was not available, a general estimate was installed as a placeholder until such time as the relevant data becomes available.

MaternalMaritalStatus
ParityOfHousehold
MaternalAge
MaternalEducation
BirthplaceOfMother
InsuranceType
IncomeType
MotherRatingOfSupport
MaternalDisease
DeliveryMode
MedicalAssistanceAtDeliv
GestationalAge
BirthWeight
APGARScoring
Gender
Race
LengthOfStay
BreastfeedingAtDischarge
PrenatalCare
FacilityAtBirth

Figure 4.3.1.1: List of Attributes Assigned in Simulation Model

Name	Position	Part	Time	Attribute Na	Attribute Va
Discharged	1	Infant		PEN	0
				ICON	147
				LENGTH	1.000
				WIDTH	1.000
				HEIGHT	1.000
				STAGE	0
				PreInterventio	0
				PostInterventi	0
				FinalCost	0
				MaternalMarit	"Married"
				ParityOfHous	"Multi-Parous"
				MaternalAge	"18-34 years"
				MaternalEduc	"High School+
				BirthplaceOf	"Born in the U
				InsuranceTyp	"Other"
				IncomeType	"Salary"
				MotherRating	"Poor"
				MaternalDise	"Yes"
				DeliveryMode	"Vaginal"
				MedicalAssist	"No"
				GestationalA	"37+ Weeks"
				BirthWeight	"2500+ grams
				APGARScori	"Poor"
				Gender	"Male"
				Race	"White"
				LengthOfStay	"48+ Hours"
				Breastfeedin	"No"
				PrenatalCare	"Adequate"

Figure 4.3.1.2: Attributes Assigned to an Infant in Simulation Model

Following the assignment of each infant's attributes, an infant is then assigned towards one of three groups: Readmit, Discharge, and Infant Mortality, Figure 4.3.1.3. Those infants that are classified as discharged will be discharged from the hospital and receive no further readmissions within the first 28 days of life. They will also not contribute to the infant mortality rate. Those infants assigned to Infant Mortality at this stage are infants that die before ever leaving the hospital. Infants that are assigned to infant readmission then go on to illness assignment where they are passed on to one of six illnesses. In each illness category, the same process is followed.

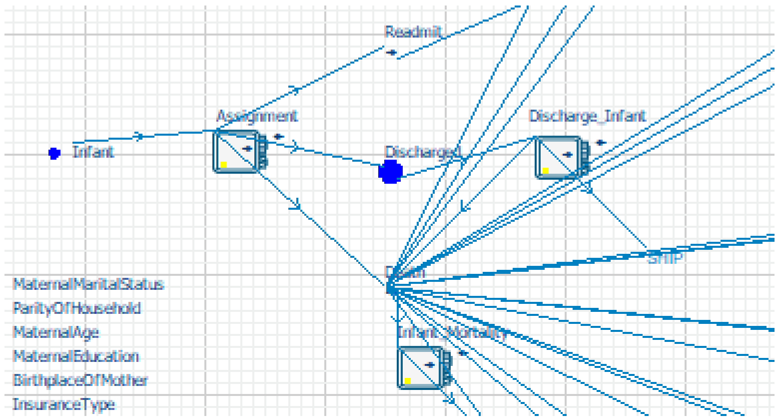

Figure 4.3.1.3: Initial Assignment of Infant into Readmit, Discharge, and Infant Mortality

Using Jaundice as the assigned illness, the following process occurs. First an infant is assigned a pre-intervention cost. This cost is assigned based on a triangle distribution with a minimum, mode, and a maximum based on available literature numbers. In this step, there is also a built in mechanism to allow for intervention testing. This is done based upon a percent upon which infants can be divided into two categories: prevented and not prevented. If no intervention is being tested, then setting the prevented percent to a very small number such as .0000001 will allow the system to run as is without removing part of the code. If an intervention is being tested, the percent of infants that are prevented from readmission would be those infants that may have been readmitted without some intervention. Prevented readmissions are assigned a new cost, Figure 4.3.1.4. This cost could either increase or decrease based upon the results of an individual case study. This new cost is the final cost for a prevented readmission. Prevented readmissions are then either discharged without further entry to the hospital, or they are added to infant mortality. Infants that die at this phase are those that have been discharged once from the hospital but were never readmitted before death.

Infant	PEN	0
	ICON	147
	LENGTH	1.000
	WIDTH	1.000
	HEIGHT	1.000
	STAGE	0
	WithoutInterve	7745
	WithInterventi	6970
	FinalCost	6970

Figure 4.3.1.4: Assignment of With and Without Intervention Costs

If the infant is sent through the not prevented group, the without intervention cost is assigned as the final cost. The infant is then sent to be discharged without further readmission or incidence or discharge with an outcome of infant mortality. An infant that passes away at this stage is an infant that has been discharged, readmitted, then discharged without further readmission before death occurs. If an infant is not discharged at this stage, it can also be assigned to infant mortality prior to discharge. This would indicate that an infant was discharged and readmitted, but that it passed away prior to discharge. This entire process is repeated individually for all six illness cases, one shown in Figure 4.3.1.5, and each illness case can be modified individually to allow the user to tailor information for or from case studies or ‘what if’ analyses.

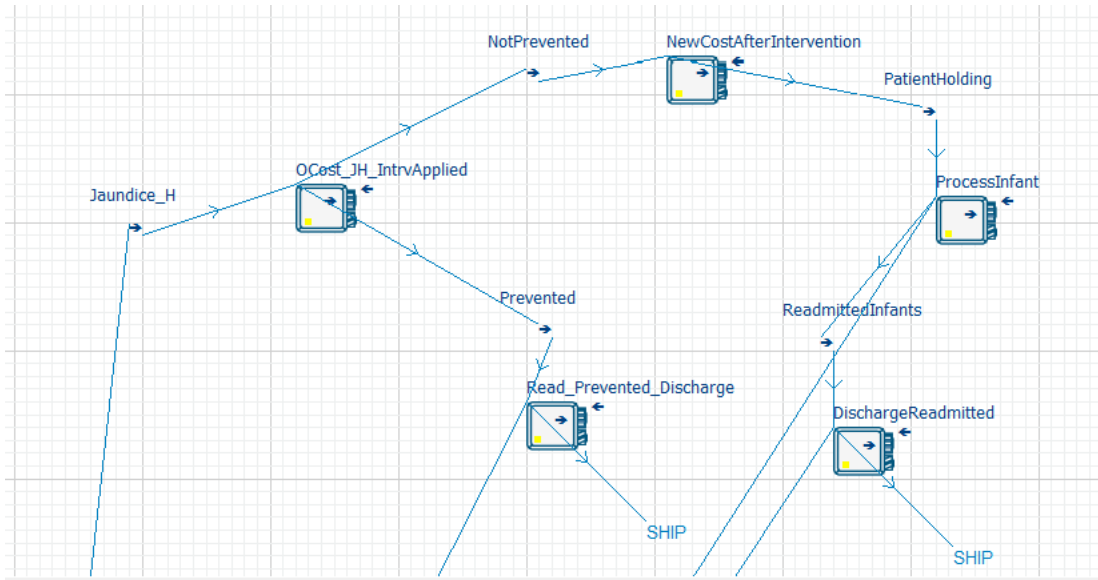

Figure 4.3.1.5: Assignment of Illness Type in Simulation Model

As the model runs, a series of variables automatically updates to allow the user to track multiple points of interest. Among these variables are three defined variables for intervention costs. TotalW_OInterventionCost depicts the original assigned value if no intervention is attempted for all infants that are readmitted. Total_Overall_Cost is defined as the with intervention cost that is assigned to all infants that were not prevented from being readmitted. This cost may either increase or decrease based on case study results. InterventionCost Savings is the third intervention cost variable and depicts the difference between the without intervention costs and the with intervention costs.

There are seven additional variables. NumberOfInfantDeaths tracks the total number of infants that have an outcome under infant mortality. The remaining six variables track the costs for each individual illness type. Additionally, running averages are given for each illness category for individual case costs as well as for overall illness case system costs. An example of these variables appears in Figure 4.3.1.6.

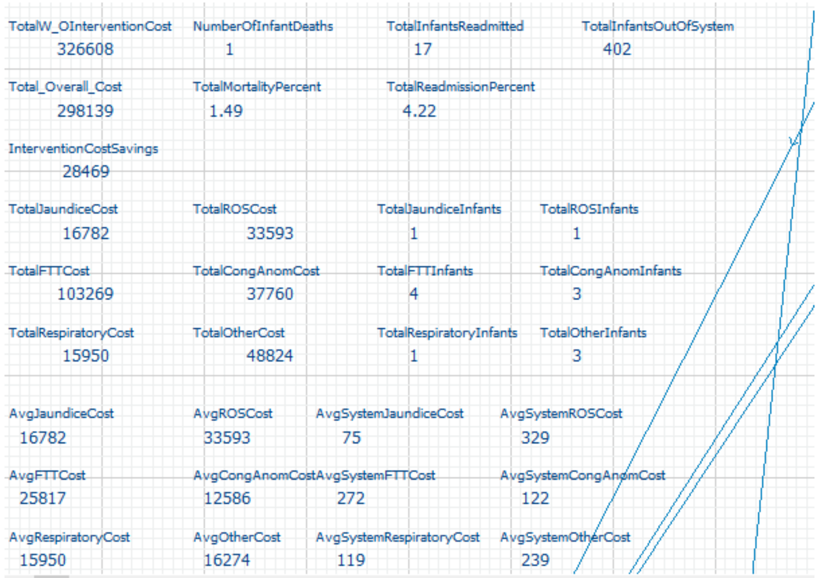

Figure 4.3.1.6: Simulation Model Variables Example

The purpose of this simulation model is to allow a practitioner to view a close approximation of the readmission and mortality system. With this base system, additional information could be collected to model the base system, the model as it stands, on the system of interest, the hospital or healthcare system being studied. With this information, practitioners could view how small-scale case studies could be applied to larger systems. Estimates for cost savings could also be approximated via ‘what if’ analyses for a variety of intervention attempts.

4.4 C Based Program

4.4.1 Current System

The C based program is designed to allow the user to perform data analysis on data collected from case studies to later be used in populating the simulation program. The calculation of odds ratios and their corresponding confidence limits allows the researcher to determine which factors to include in a model for further study versus those that are unlikely to affect the overall system. Additionally, the program also contains the ability to store data and information, so results from previous research or case studies can also be easily contained within the program for easy access at a later time. This could also include ideas for future case studies, methods, processes, and research recommendations or results. This program has very simple instructions and could therefore be used by anyone with a basic understanding of the purpose and use of odds ratios and confidence intervals.

The C based program is divided into two modules, a data analysis module and an information and data storage and retrieval module shown in Figure 4.4.1.1.

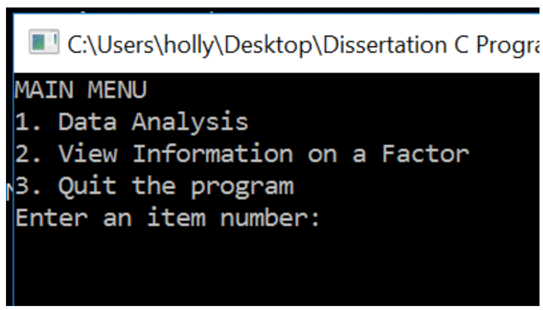

Figure 4.4.1.1: C Program Main Menu

The data analysis module is broken down into four sub-areas, Figure 4.4.1.2. The first of these areas is Choose Factors of Interest. When a practitioner goes to enter data into the data analysis module, they must first choose which factors they will be studying. Currently, several example categories, factors, and values are loaded into the program. Categories are overarching, broad categories into which factors are classified and can include maternal characteristics, infant characteristics, hospital characteristics, delivery characteristics to name a few. Factors are then assigned to a category. An example of this could be gender and race. Both of these factors would be considered infant characteristics. Furthermore, each factor contains two or more values. The values for gender, for example, would be male and female.

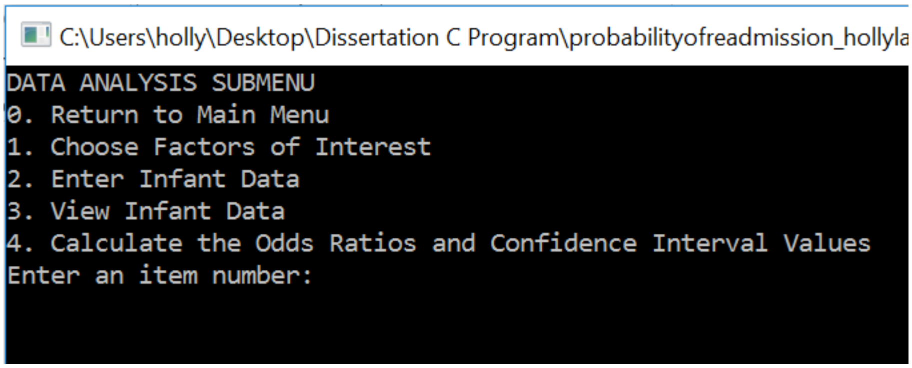

Figure 4.4.1.2: Data Analysis Submenu

All factors that have been loaded into the system will be available for selection, Figure 4.4.1.3. Currently these factors include gender, race, birth weight, delivery mode, drugs administered during birth, and facility of birth. In this manner, the practitioner can choose to focus on a smaller case study of only a few factors at a time or a large case study containing all factors without having to add or remove factors between studies. The user would select the factors that they wish to study and any factors not selected would not be prompted during data entry.

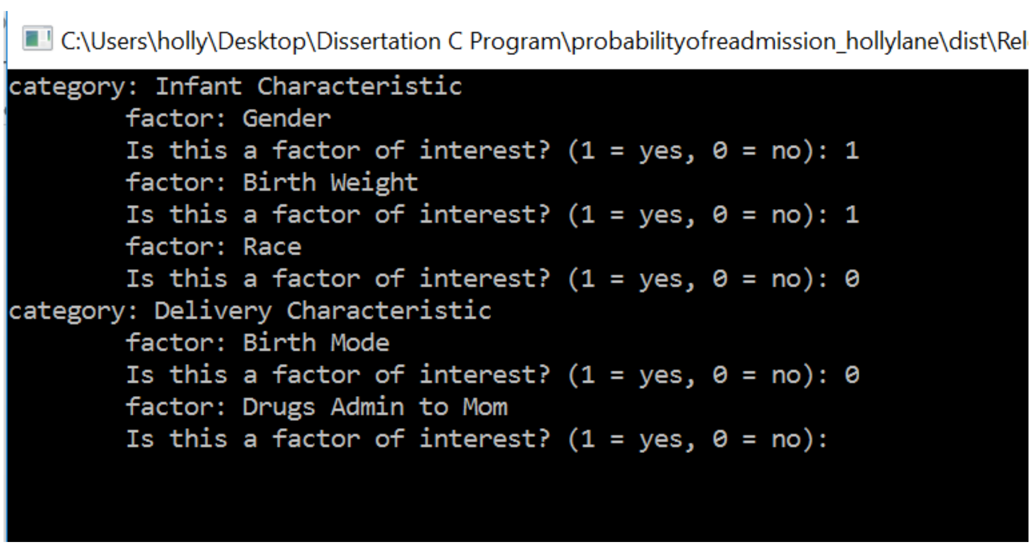

Figure 4.4.1.3: C Program - Choose Factors of Interest Function

The second subsection of the data analysis module is the Enter Infant Data area, Figure 4.4.1.4. In this area, the user will be prompted to choose whether the infant was readmitted. After choosing the readmission status, the user will then be prompted to enter the value for each factor that was chosen to be of interest in the previous subsection. This step may be repeated as many times as necessary via the program or can be done in a text file first and then opened in the program as long as the format is followed correctly. Upon completion of the data entry, all entered infant data may be reviewed in subsection three, View Infant Data. If any data point requires editing, this may be done in the text file which is automatically saved in the output folder.

```
C:\Users\holly\Desktop\Dissertation C Program\probabilityofreadmission_hollylane\d
Was this infant readmitted? (0 = no, 1 = yes): 1
category: Infant Characteristic
        factor: Gender
                1. value: Female
                2. value: Male
                Select a value for this factor: 1
        factor: Birth Weight
                1. value: less than 1 pound
                2. value: 1 to less than 2 pounds
                3. value: 2 to less than 3 pounds
                4. value: 3 to less than 4 pounds
                5. value: 4 to less than 5 pounds
                6. value: 5 to less than 9 pounds
                7. value: greater than 9 pounds
                Select a value for this factor: _
```

Figure 4.4.1.4: C Program - Enter Infant Data Function

The final subsection of the data analysis section is the Calculate Odds Ratios and Confidence Interval Values. The first thing that will happen upon selection of this subsection is that the program will prompt the user to indicate which value of the factor will be viewed as the reference. In this area, calculations are automatically loaded for all factors that have been entered. If any factors contains insufficient information for the calculations to be completed it will read out that not enough information is present. Reference values are also indicated as such, Figure 4.4.1.5. This information indicates to the practitioner whether there is an increased or decreased likelihood for readmission for infants with this factor compared to the reference group. This formulation follows the method used in Essential Med Stats (n.d.).

```
Infant Characteristic->Gender->Female    OR = 1.000000   CI = This is the reference value.
Infant Characteristic->Gender->Male      OR = 0.300000   CI = 0.032571 to 2.763228
```

Figure 4.4.1.5: C Program - Odds Ratio and Confidence Interval Calculation

In the information and data storage and retrieval module, there are two options. The first of these is to view information for a factor, Figure 4.4.1.6.

```
C:\Users\holly\Desktop\Dissertation C Program\probabilityofreadmission_hol
1. Infant Characteristic - Gender
2. Infant Characteristic - Birth Weight
3. Infant Characteristic - Race
4. Delivery Characteristic - Birth Mode
5. Delivery Characteristic - Drugs Admin to Mom
6. Hospital Characteristic - Hospital of Birth

SELECT FACTORS TO VIEW DETAILED INFORMATION FOR
(0 TO Return to VIEW DETAILED FACTOR INFORMATION SUBMENU)
```

Figure 4.4.1.6: View Detailed Information for Factors Menu

This will prompt the user to choose the factor they would like to view. At this point, the text file for this factor will be opened, Figure 4.4.1.7. Information can be stored in this text only file at the user's discretion and could include previous research, gathered data, or notes of any kind.

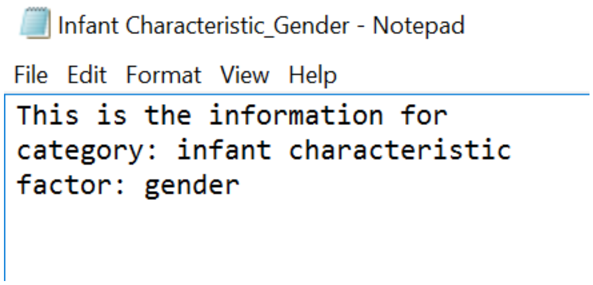

Figure 4.4.1.7: Pop Up of Text File for Information Display

The second subsection is the View list of all factors, which will display a complete list of all factors that have been loaded into the system, Figure 4.4.1.8.

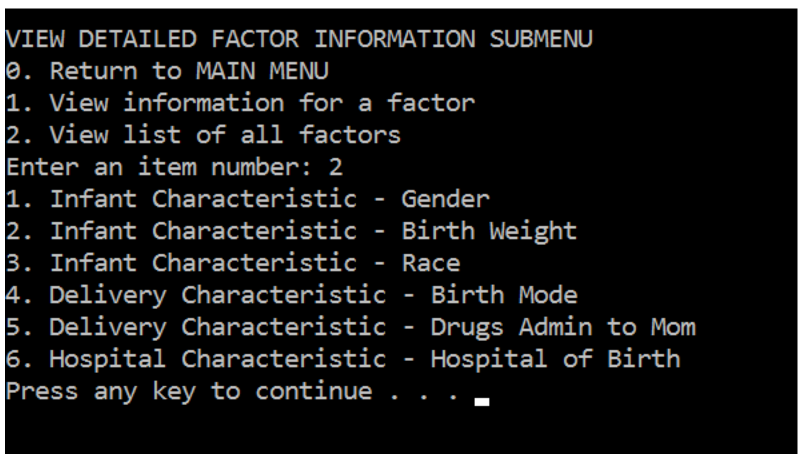

Figure 4.4.1.8: C Program - View List of All Factors Function

CHAPTER 5
FUTURE WORK

This chapter summarizes options for additional research related to this dissertation.

5.1 Future Work

In the future, the simulation model could be expanded to allow for factor interaction data. This would allow the model to assign specific odds for readmission to infants based upon their assigned ‘attributes’. Handling interactions between attributes requires an exponential number of minor calculations to be performed by the model. This information would be more difficult to obtain for large case studies but would allow for increased accuracy and targeting in the model. This information could then be used to create specific, targeted interventions that would allow for the highest degree of precision when targeting for a specific effect such as the reduction of infants readmitted for jaundice or the determination of whether or not a specific intervention might cause an increase in neonatal mortality due to reduced readmissions for those infants that were most vulnerable to adverse outcomes.

To this effect, the C based program could have an additional module added to automatically calculate interaction data from a recorded data set. This would reduce the number of calculations that the practitioner would have to do manually. Further information in this area would allow for a singular odds ratio to be developed that could define the likelihood of an infant’s odds for readmission allowing practitioners to target infants that would be at risk for increased readmissions or at risk for adverse health outcomes due to financial or family circumstances which might cause the infant’s provider to not seek care for the infant when it is needed.

Additionally, a module for data and information storage and retrieval could be added that could allow for the selection of multiple factors together. i.e. The user could open the information storage for Gender and Race. Given that the data and computational requirements climb so quickly, this type of information would be best used in small studies where a high degree of accuracy is required.

Additionally, case studies on a larger scale could be performed to obtain more accurate system data for use in both the program and simulation model. As much of the data needed is either inaccurate or unavailable, a case study would be required to rectify this issue. Further case studies could be done to test the effects of phone, email, or texting based interventions to determine the most appropriate form of an intervention and could then be expanded even further to test individual cases for specific wordings or visuals in education based interventions. Hospitals could also attempt case studies at different facilities to determine what, if any, hospital policies or procedures contribute to or guard against adverse infant health outcomes, and results could be shared between facilities to improve the likelihood for reducing those areas such as cost and readmissions which are important to healthcare personnel while also ensuring that these considerations do not lead to an increase in adverse outcomes or decrease in quality of care.

CHAPTER 6
CONCLUSION

This chapter summarizes the results and conclusions of this dissertation.

6.1 CONCLUSION

The combined analysis methods as presented in this research along with the simulation model and C program can provide a framework to assist healthcare professionals in a more informed decision making process. They will have the ability to structure and develop intervention methods for reducing adverse outcomes, costs, and many other effects. They can then test these interventions with the simulation model to test various hypotheses or enact these interventions in real world case studies. Data from case studies can then be used with the C program to analyze the collected data and further research into how a specific hospital or healthcare system behaves. This information can then be used to repopulate the simulation model to increase the accuracy of the simulation and provide even further information to allow for subsequent interventions. These tools will allow healthcare professionals to take an in-depth look at infant readmission and mortality in order to target specific illnesses, factors, or interventions to the population of study.

The method for combining categories and creating forest plots can allow practitioners to continue research into determining how factors are related to readmission and mortality, and if paired with future work, could allow for the analysis of combined factor effects for even more accurate modeling and eventually for predictive methods for determining the risk for individual or groups of infants. This data would further allow practitioners to make more informed decisions for “at risk” infants were given the requisite attention to promote positive health outcomes.

Appendix A

Simulation Instructions

A.1 Simulation Instructions

To open the simulation model, the user should open Witness, click open model, and double click on the simulation model file.

In the simulation model, there are several areas that can be quickly and easily changed. The same process is generally used across the model but will be quickly described.

To change an attribute category label or probability, right click on infant, click on detail, then click on actions on create. Attribute labels can be changed within the boundaries of the " ". Probabilities can be changed simply by replacing the numbers. Then click validate and close out of the dialog box.

To change assignment percents, right click on the machine where the assignment is made, click detail, then click output rule. Percentage numbers can then be replaced as desired. Click validate then exit dialog box.

To change the triangle distribution for cost at the illness assignment, select one of the IntrvApplied machines, right click for detail, click actions on start. Numbers may then be replaced in minimum, mode, maximum order. This distribution is a placeholder until further study can be conducted and the correct distribution for this area identified and added.

To change new costs after intervention, select the appropriate machine, right click, select detail, then actions on start. Replace the percentage as appropriate. Click validate then close dialog box.

Appendix B

C Program Instructions

B.1 C Program Alteration Instructions

To open the C based program, the user should double click on the .exe file, which will prompt the program to open and execute.

To open the example data file, go to OutputFiles then right click on the text file Example Data Set. Click copy.Return to main file containing the .exe file. Right click the .exe file and click paste. The program will automatically open and will show the data file has been entered. This file will allow the user to view an example of odds ratio and confidence interval calculations for the factor gender if this option is selected from the main menu. If the user wishes to view an example of the view factor files, information is available for the factors gender and race.

In the main folder of the C program, there are four files: descriptions, outputFiles, config, and probabilityofreadmission. The first file that can be altered is the config file. This is a text only file from which categories, factors, and values may be entered. The category refers to the type of factor and can be divided into such categories as infant characteristic, delivery characteristic, maternal characteristic, ect. Each category need only be added once and is defined by 'category = Infant Characteristic'. Beneath a category value all factors for that category and all values for each factor will be listed. All factors and values will be called under that category until the next category is listed. A factor can be assigned to a category via 'factor = gender'. Beneath that factor will be all available values. In the case of gender, 'value = Female' and 'value = Male' would be added as the available options. Each defined category, factor or value should appear on a new line. Categories, factors and values are nested, so a category will appear first followed by a factor and then all factor values. If additional factors are required in the same category, then the next 'factor =' is assigned directly following the last 'value =' of the previous factor.

For each factor that is defined, a file must then be created to store related factor information. This is done by entering the descriptions folder. Once there, the file must be named with the category name then the factor name separated only by an underscore. For example: Infant

Characteristic_Gender. This file should be a plain text file only. Information can be added or removed from these same files by opening a file, adding or removing text, then resaving the file.

In the outputFiles folder, an data that is entered into the program is automatically saved with a date and time stamp. These files can be edited to add or remove points via the text only file in the date/time subfolder. Edited data must be in the exact same format as it exists upon the original creation of the file, or the file will no longer work. If it is desired to reopen a previous file, the user would enter the date/time subfolder, right click and copy the text file only, return to the main folder, right click on the .exe file and click open. The program will then open with the desired data set. No further alteration to the program, can easily be made and should be avoided as much as possible.

<u>B.2 C Program config.ini Nesting Example</u>

```
category=Infant Characteristic
factor=Gender
value=Female
value=Male
factor=Birth Weight
value=less than 2500 grams
value=greater than 2500 grams
factor=Race
value=African American
value=Caucasian
value=Hispanic
value=Native American
category=Delivery Characteristic
factor=Birth Mode
value=Caesarean
```

value=Vaginal

factor=Drugs Admin to Mom

value=drug1

value=drug2

value=drug3

category=Hospital Characteristic

factor=Hospital of Birth

value=hospital A

value=hospital B

value=hospital C

value=hospital D

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