ABSTRACT

GÜLTEKİN, MÜGE. Using Voronoi Diagram for Allocation of Acute Care Beds in North Carolina in the Light of Certificate of Need Law. (Under the direction of Prof. Stephen D. Roberts and Prof. Reha Uzsoy.)

Geographic barriers can challenge the ability of health systems to allocate health care resources equitably according to need. This study employs Voronoi diagrams to create hospital service areas for the acute care hospitals in North Carolina that provide geographical equity, and computes the acute care bed needs of each service area based on their the population density.

The planning of acute care beds in North Carolina is done by the State Medical Facilities Plan (SMFP). This process was previously based on a statewide average growth rate and, later, on a county-specific growth rate without aggregating counties with small hospitals in the 2011 SMFP. This research is fundamentally different from the current approach since the allocation of beds is not affected by county boundaries, but instead defines a region of geographic equity using Voronoi diagrams by matching acute care beds to demand.

We provide two applications of Voronoi diagrams for the acute care beds in North Carolina. The first application in this study focuses on the size of the existing facilities and does not include the allocation of beds to new facilities, or recommend any new facilities while the second application compares proposed acute care beds and acute care hospitals. With the second application, we demonstrate that the Voronoi diagrams and related calculations can be used to compare different proposed projects.

Finally, using Voronoi diagrams ensure geographic equity under the assumption of the equity of care provided by each bed. The population in this region determines the number

of acute care beds and thus determines acute care hospital capacity. This capacity is not confined to county boundaries, but includes all the population in the service area.

This study also shows that Voronoi diagrams can be applied to one of the most important considerations in healthcare delivery, which is population-based service area.

Using Voronoi Diagrams for Allocation of Acute Care Beds in North Carolina in the Light of Certificate of Need Law

by
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DEDICATION

To four pillars of my life: my mother, my father, my sister and my husband…

BIOGRAPHY

Müge Gültekin was born in Izmir, Turkey on 12th of July 1985. In August 2009, she received her Bachelor of Science degree in Industrial Engineering from Dokuz Eylul University in Izmir, Turkey. Since August 2009, she has been a graduate student at North Carolina State University, and has received research assistantship during her studies. She is expected to receive her Master of Science degree in Industrial Engineering in 2012.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

Introduction

The North Carolina State Facilities Plan, which is developed by the North Carolina Department of Health and Human Services' Division of Health Service Regulation, is published at the beginning of each calendar year. The major purpose of this plan is to inform individuals, institutions, state and local government agencies, and community leadership about policies and projections of need for the different healthcare services that are regulated by the state. This plan, which is a key resource for this research, is also used to guide local planning for specific health care facilities and services. The specific facilities and services that are subject to regulation through this plan are:

- acute care hospitals
- operating rooms
- inpatient rehabilitation facilities
- technology services
- nursing care facilities
- adult care facilities
- Medicare-certified home health agencies
- end-stage renal disease dialysis facilities
- hospice home care and hospice inpatient beds
- psychiatric hospital units and specialty hospitals
- substance abuse hospital units, specialty hospitals,
- and residential facilities

- intermediate care facilities for people with mental retardation

The planning of acute care beds, which is the focus of this research, is usually done through an allocation of needed acute care beds through a series of planning meetings. The allocation method used in this research attempts to match acute care beds to demand. The purpose of this research is to show how to compute the number of acute care beds and acute care days required at a specific location using Voronoi diagrams, with primary emphasis on achieving geographic equity in access to acute care beds. In this research, geographic equity is achieved when all individuals in the population is associated with the closest hospital and that hospital has sufficient capacity to serve its allocated population.

1.1. Concepts and Definitions

A number of important concepts need to be described relative to this research. These include the definitions of concepts related to Certificate of Need (CON), Voronoi diagrams and acute care beds.

1.1.1. Certificate of Need (CON)

State governments seek to reduce overall health and medical costs. For this purpose, as of mid-2008 about 36 states retained some type of Certificate of Need (CON) program, law or agency (National Conference of State Legislatures) which attempts to restrain health care facility costs by requiring coordinated planning of new services and construction.

The planning of health systems in the State of North Carolina is done through the North Carolina Certificate of Need (CON) law. This law restricts unnecessary increases in health care costs and limits unnecessary health services and facilities based on geographic, demographic, and economic considerations. This is accomplished by forbidding health care providers from acquiring, replacing, or adding to their facilities and equipment, except in specified circumstances, without the prior approval of the State's Department of Health and Human Services. At the beginning of each calendar year, the Medical Facilities Planning Section of DHSR publishes a new State Medical Facilities Plan (SMFP) which includes the maximum number of health service facility beds, by category, acute care services, operating rooms, home health offices, and other services that may be approved by the Certificate of Need (CON) Section.

The stages of the CON process are as follows:

- **Allocation of Beds and Services**: The first stage is accomplished by proposing the State Medical Facilities Plan published at the beginning of each calendar year. By this plan, the Medical Facilities Planning Section of DHSR sets the maximum number of health service facility beds by category, operating rooms, home health offices, and other services that may be approved by the Certificate of Need (CON) Section.
- Review Schedule Pre-Application Procedure
- Application Submittal
- Public Comment Period
- Public Hearing
- Application Review
- Appeals of Decision
- Monitoring

The whole process takes from 180 to 250 days, as pointed out in the State Medical Facilities Plan.

This study concentrates on the first step, the allocation of beds and services for acute care hospitals. Current allocations are based on the existing bed allocation and population in each county within the state. The geographic boundaries of the counties have been determined by various economic, political, and geographic considerations. However, people seeking health care are not confined by county borders. This research is fundamentally different in its approach to the allocation of beds since it is not limited by county boundaries and instead defines a region of geographic equity.

1.1.2. Voronoi Diagram

A Voronoi diagram is a decomposition of a metric space determined by distances to a specified discrete set of points in the space. In the simplest case, we are given a set of points *S* in the plane, which are the Voronoi sites. Each site *s* has an associated **Voronoi cell** *V(s)* consisting of all points in the space that lie closer to *s* than to any other site.

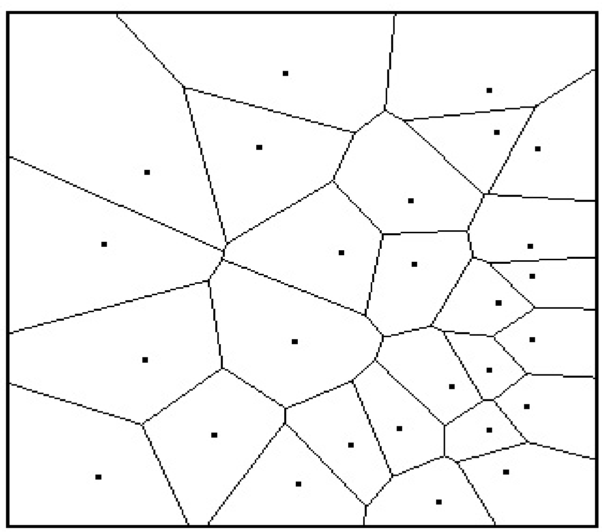

Figure 1.1: Voronoi Diagram

In other words, each point in a Voronoi cell has a minimal maximum distance to the associated Voronoi site. A Voronoi Diagram consists of a number of Voronoi cells. In this study each Voronoi site, or center point, represents an acute care hospital. More detailed information on Voronoi Diagrams will be given in Chapter 3 of this thesis.

1.1.3. Some Concepts Related to Acute Care Beds

According to Office of Statewide Health Planning and Developments

Acute care beds: Acute care beds are defined as beds accommodating patients in a hospital or hospital department whose average length of stay is 30 days or less until the 1980s, and 18 days or less in more recent years. Acute care beds are beds accommodating patients where the principal clinical intent is to do one or more of the following:

- manage labor (obstetric)
- cure illness or provide definitive treatment of injury
- perform surgery
- relieve symptoms of illness or injury (excluding palliative care)
- reduce severity of illness or injury
- protect against exacerbation and/or complication of an illness and/or injury which could threaten life or normal functions
- perform diagnostic or therapeutic procedures.

Average length of stay by inpatient and acute care: Average length of stay is computed by dividing the total number of days stayed (from the date of admission in an inpatient institution) by the number of discharges (including deaths) during the year.

Total inpatient care beds: A total inpatient care bed refers to the average daily census or mid-year count of the available beds in all public and private inpatient institutions.

Discharge: Discharge is the formal release of an inpatient from an acute care institution after a period of "hospitalization". It includes deaths in hospitals, but excludes same-day separations and transfers to other care units within the same institution.

According to the State Medical Facilities Plan, acute care hospitals aim:

- to facilitate continuing improvement in the State's acute care services,
- to expand the availability of appropriate, adequate acute care service to the people of North Carolina,
- to protect the resource that the State's acute care hospitals represent,
- to encourage the substitution of less expensive for more expensive services whenever feasible and appropriate,
- to assure that substantial capital expenditures for the construction or renovation of health care facilities are based on demonstrated need, and
- to assure that applicants proposing to expand or replace acute care beds should provide careful analysis of what they have done to promote cost-effective alternatives to inpatient care and to reduce average length of stay.

1.2. Scope and Objective of the Research

As mentioned earlier, this study is concerned only with the planning of acute care hospitals in North Carolina. In this study, the allocation is performed by matching acute care beds to demand, where the number of acute care beds is determined by the population in service area of the hospital. This work presents two applications of Voronoi diagrams for health care facilities. The first application focuses on the size of existing facilities and does not include the allocation of beds to new facilities, or recommend the construction of new facilities, while the second compares proposals for addition of new beds to the existing facilities or construction of new facilities.

The state-wide planning of acute care beds is done through the State Medical Facilities Plan (SMFP) by the North Carolina Department of Health and Human Services, Division of Health Service Regulation. According to the 2010 State Medical Facilities Plan, there were 114 licensed acute care hospitals and 20,443 licensed acute care beds in North Carolina, as of June 2009. Data provided by Thomson (formerly Solucient) indicated that 4,511,555 days of care were provided to patients in those acute care hospitals during 2008, representing an average annual occupancy rate of 60.29 percent, excluding beds in service for substance abuse, psychiatry, rehabilitation, hospice, and long-term care. In addition, acute care bed capacity across the state is expected to increase in certain markets by 825 pending beds and to decrease in other markets by 375 beds, for a net increase of 450 beds. It is important to note that not all licensed beds were in service throughout the year. Some beds were permanently idled, while others were temporarily taken out of service due to staff shortages or to accommodate renovation projects.

We obtained most of the data from the State Medical Facilities Plan since we want to be consistent with the current Certificate of Need process, except in using a different allocation method to obtain the computed acute care beds capacity for each hospital and acute care days. Our methodology employs Voronoi diagrams to determine hospital service areas that provide geographic equity and then computes the bed needs from the population density in those service areas.

Geographic barriers can challenge the ability of health systems to allocate health care resources equitably according to need. Difference in population is a result of these barriers. The SMFP had previously been using a statewide average population growth rate. This was changed in the 2011 SMFP to the use of a county-specific growth rate without aggregating counties with small hospitals. This improvement does not seem sufficient because there are some counties with one hospital, some with multiple hospitals, and even some without any hospital. Hence a county-specific growth rate might provide insufficient information. To overcome this kind of inequity, we use a hospital based growth rate, which will be presented as the Voronoi population. After developing the Voronoi diagrams for acute care hospitals, we compute the Voronoi population based on all the census tracts inside the Voronoi region whose center point is that specific acute care hospital. By avoiding restrictions due to county boundaries, the population served by any hospital may improve geographic equity. By using census tracts, rather than counties as the population base, the population density is measured to a finer resolution.

The main objective of this thesis is to ensure that geographic equity is maintained by determining the number of acute care beds needed and number of acute care days expected for each hospital. The results, when compared to existing bed allocations, suggest how geographic equity can be improved through the allocation of new beds or the reallocation of existing beds. Another objective of this study is to show how Voronoi diagrams can be applied for different types of health care facility allocation problems. Of course the politics of bed allocation is not addressed by this research and remains a significant factor in bed allocation policy decisions.

We use our proposed approach to assess the equity of access to acute care hospital beds in the State of North Carolina. Using the average of maximum distances to access an acute care bed in a service area as a measure of equity, we compare the current allocation of acute care beds to existing hospitals to that arising when our proposed approach is used to determine service areas. For the second application of our study, which is about comparing different proposals for adding acute care beds or new acute care hospitals for pre-specified areas, we use both average of maximum distances and the total squared deviation of per capita of acute care beds in a service area from the statewide average as a measure of equity. Our results indicate that using the Voronoi approach to estimate service areas results in a significantly lower average maximum distance to access a health care facility than is the current approach.

1.3. Organization of the Thesis

This thesis is organized as follows.

Chapter 2 reviews some studies of locational equity, health planning, hospital location-allocation for improving geographic equity, Voronoi diagrams, and optimization using Voronoi diagrams.

Chapter 3 presents the methodology of the research. It includes a step by step description of the current method of bed allocation used by the Division of Health Service Regulation in preparing the SMFP, and a more detailed description of Voronoi diagrams and their basic properties. We compare the results of the SMFP bed allocation and that obtained using the Voronoi diagram. We also describe the population calculations used in the thesis in conjunction with the Voronoi diagrams.

Chapter 4 presents the applications of Voronoi diagrams for the acute care hospitals in North Carolina. This chapter describes our assumptions, and the Matlab tools that we used to draw maps and perform the calculations. Results and discussion of the application explained in Chapter 4 are presented in this chapter.

Conclusions and recommendations for future studies are presented in Chapter 5.

CHAPTER 2

Literature Review

The literature presented in this chapter includes an overview of health care planning, Voronoi diagrams applications and their applications for optimization. The information used in this literature review came from journal publications, internet resources, and books.

2.1. Health Care Capacity Planning; Hospital Location & Location-Allocation

With Certificate of Need laws and the "Hospital and Medical Facilities Act of 1946" (better known as the Hill-Burton Program) an extensive body of literature has focused on capacity management or location-allocation decisions in health care sector (Berghmans et al., 1984), (Smith-Daniels et al., 1988), (Segall, 1992) and (Stummer et al., 2004). In 1996, Levit et al. pointed out that hospital payments are the largest component of personal health spending in the United States.

Location decisions in health care take on greater importance relative to other facilities in terms of the effects of their results. Thus, the number of facilities needed or the location of the facilities need to be well-planned. If the number of facilities is under-estimated, this can cause increase in mortality (death) and morbidity (disease); conversely, if the number of facilities is over-estimated, building new facilities can create needless expenses (Daskin & Dean, 2005).

There are two different approaches in the literature to optimize capacity of a health care facility: location models and location-allocation models. The following section includes some studies in these fields.

Table 2.1: Location and location-allocation models vs. variables to be calculated within the models (Oliveira, 2005)

Models	Individual hospital supply	Individual demand	Total demand
Location	Calculated within model	Independent of supply	Fixed total demand
Location-allocation	Calculated within model	Dependent on supply	Calculated within model

Dokmeci (1977), Ruth (1981), Stummer et al. (2004) and Santibanez et al. (2009) consider similar decisions for the location of health-care services where demand is assumed to occur only at specified points or areas (which are census tracts in our study), the principal metric in these problems is a function of the distance to the facilities (Euclidean distances in our study), and multiple objectives. Santibanez et al. (2009) also point out that there are no published studies describing health-care location-allocation models that explicitly consider clinical standards and describe large-scale applications with multiple services, hospitals and periods. Other than that, when the location literature applies to health care facilities, three major focal points have been mentioned: accessibility, adaptability and availability (Daskin et al., 2005). Daskin et al. (2005) present the set covering model, the maximal covering model, and the P-median model in the light of these three issues.

A large body of literature has been devoted to queuing models (Kao & Tung, 1981), (Worthington, 1987; Worthington, 1991), (Huang, 1995), (Hershey et al., 1981). These models vary in complexity and in their assumptions, and are often hospital-specific. Another group of authors have approached the bed allocation by deploying operations research techniques such as linear programming (Graves, 1986), integer programming (Ruth, 1981), forecasting (Lin, 1989) and simulation (Goldman et al., 1968), (Dumas, 1984), (Carter & Blake, 2005), (Harper & Shahani, 2002). Most of these works include simplifying assumptions that do not apply to hospital capacity planning problems. A comprehensive simulation model is presented by Harper and Shahani (2002) because of the need for a flexible and a more sufficient method for hospital capacity planning.

Access to health care services is a key issue while optimizing a health care facility. Access to health care services can refer to: availability in terms of socio-economic status or geographic location (Shuurman et al., 2008).

Regional development usually involves population growth and changes in population distribution (Peled & Schenirer, 2009). According to Santibanez et al. (2009), the composition of the population, such as size and age distribution, greatly influences health-care needs. This study showed that, according to Fraser Health, a British Columbia health authority, the projected population growth and aging effect alone would double the current demand for acute care beds by 2020 in the baseline scenario. Tanser (2006) developed a quantitative methodology to optimally site new primary health care facilities so as to achieve the maximum population-level increase in accessibility to care. To be successful, primary health care must be accessible to the vast majority of the population.

In this thesis we examine a method combining the key issues in health care facility allocation mentioned above. Our study applies Voronoi diagrams to consider geographic equity and population density. The Voronoi diagrams create service regions for each acute care hospital in North Carolina such that all points in its region are closer to that acute care hospital than to any other. This procedure determines service areas for each given facility such that all patients within the service area of a given facility are closer to that facility than to any other. Plotting census tracts allows us to calculate the population in each Voronoi polygon. More detailed description of our model will be given in the next two chapters.

Table 2.2: Qualitative description of Mathematical Programming Models for Location of Healthcare Facilities (Oliveira, 2005)

Model (and typology)	Key equity concept	Patients' behavior constraint	Supply interaction and other system constraints
DBM -Distance-based model Location model	Equity of access: minimization of total distances travelled by patients to (closest) hospitals.	Assumption that patients travel to closest hospitals, and patients are allocated to three types of hospitals in accordance with past quotas (normative).	No interaction between hospital supply and utilization of alternative hospitals. Patients make use of three hospitals: one central hospital and two other hospitals of the network.
UBM-Utilization-based model Location-allocation model	Equity of utilization by population area: minimization of sum of variations between predicted and normative utilization per population area (according to need).	Assumption that patients in each geographic area use hospitals based on fixed conditional probabilities (prescriptive).	No interaction between hospital supply and utilization of alternative hospitals. System constraints: upper and lower limits to variation in the supply of each hospital; fixed total supply. Conditional probability of use of hospital generated by a gravity model.
UFBM-Utilization flows-based model Location-allocation model	Equity of utilization flows between population areas and hospitals with the equity target defined as: flows if patients were treated in the closest hospital.	Assumption that patients in each geographic area use hospitals in accordance with the FDM developed in (Oliveira 2002) (prescriptive).	Interaction constraint as captured by the FDM constraint. System constraints: upper and lower limits to variations in the supply of each hospital; fixed total supply. Fixed probabilities of a population making use of a hospital (prediction taken from the first part of the FDM)

2.2. Voronoi Diagrams

Voronoi regions are contiguous, compact and simple to generate (Svec et al., 2007). Thus they have been used for determining mutually exclusive partitioning of space in the social and environmental sciences (Okabe et al., 2000). Okabe et al.(1997) proposed studies of Voronoi diagram for demand allocation purposes. Other studies that show how widely Voronoi diagrams can be applied are evaluation of public park locations (Lamtrakul et al., 2003), space allocation of educational centers (Karimi et al., 2009), coverage optimization for directional sensor networks (Li et al., 2009) and sequential location-allocation of public facilities (Suzuki, 1991).

Given a finite set of distinct, isolated points in a continuous space, the Voronoi diagram associates all locations in that space with the closest points. Voronoi and Dirichlet independently proposed the mathematical fundamentals of this technique (Okabe et al., 2000). The Euclidean metric is the applied distance function in most cases. There are also some studies using the Manhattan metric or the uniform metric as distance function (Svec et al., 2007).

Okabe et al.(2000) discuss locational optimization using Voronoi diagrams under three headings: locational optimization of points, locational optimization of lines, and locational optimization over time. Locational optimization denotes problems related to points in a plane or in a space, where the points represent point-like facilities, service points, observation points, or points from which some influential power is generated. Okabe et al.(2000) present:

- locational optimization of point-like facilities used by independent users

- locational optimization of points in a three dimensional space
- locational optimization of point-like facilities used by group
- locational optimization of a hierarchical facility
- locational optimization of observation points for estimating the total quantity of a spatial variable continuously distributed over a plane
- locational optimization of service points of a mobile facility
- locational optimization of terminal points through which users go to the central point, locational optimization of points on a continuous network

Okabe et al. (2000) present locational optimization of lines as locational optimization of a service route, locational optimization of a network, and Euclidean Steiner minimum tree. When time is considered, Okabe et al.(2000) proposed multi-stage locational optimization and periodic locational optimization. In addition to these studies, Okabe et al. (1997) developed a survey of location problems formulated as Voronoi problems. They emphasize that Voronoi diagrams are useful both for constructing a computational method and obtaining good behavioral implications. The computational methods proposed by Okabe et al. (1997) are presented in Table 3.

Optimal coverage in directional sensor networks discussed by Li et al. (2009) is another good example of the use of Voronoi diagram. Since the goal of optimal coverage in directional sensor network is covering the maximum area while activating as few sensors as possible, a Voronoi-based centralized approximation algorithm, which requires global information, and a Voronoi-based distributed approximation algorithm, in which each sensor must make its decision independently based only on local information gathered from its neighbors are presented in this study.

Table 2.3: Locational optimization problems solved through Voronoi Diagrams for points, lines and areas (Okabe & Suzuki, 1997)

through points	through lines	through areas
• **P1(largest empty region problem):** • P1(largest empty circle problem) • P1(largest empty convex region problem) • P1 in which *S* is a sphere (denoted by $\mathcal{S}$); s_i is a point-like facility p_i; • P1 in which *S* is a finite network (denoted by $\mathcal{N}$); s_i is a point-like facility p_i • **P2(smallest enclosing region problem):** • P2(smallest enclosing circle problem) • **P3(bottleneck problem):** • P3 in which $S = \mathcal{R}^2$; s_i is a point-like facility p_i • **P4(continuous p-center problem):** • P4 in which $S = \mathcal{R}^2$; s_i is a point-like facility p_i • P4 in which *S* is a sphere, $\mathcal{S}$; s_i is a point-like facility p_i • P4 in which S is a network, $\mathcal{N}$; s_i is a point-like facility p_i • **P5 (continuous p-median problem):** • P5 in which *S* is a bounded region $\mathcal{R}^2$; s_i is a point-like facility • P5 in which facilities form a hierarchy, such as a system of post offices consisting of the main office and branch offices. • P5 in which *S* is a network, $\mathcal{N}$; s_i is a point-like facility p_i • P5 in which *S* is a bounded region $\mathcal{R}^2$; s_i is a point-like facility p_i, $d(p,p_i)=d_w(p,p_i)=d_E(p,p_i)+w_i$ is the weighted distance • **P6 (Voronoi fitting problem)** • **P7(lattice fitting problem)**	• P1(largest empty circle problem for lines) • P2 in which $S = \mathcal{R}^2$; s_i is a line-like facility (denoted by l_i) • P3 in which $S = \mathcal{R}^2$; s_i is a line-like facility (denoted by l_i) • P4 in which $S = \mathcal{R}^2$; s_i is a line-like facility (denoted by l_i) • P5(continuous p-median problem for line-like facilities) • **P8(label fitting problem)**	• P1(largest empty circle problem for areas) • P2 in which $S = \mathcal{R}^2$; s_i is an area-like facility represented by a polygon • P3 in which $S = R2$; s_i is an area-like facility represented by a polygon • P5(continuous p-median problem for area-like facilities)

We can also extend the concept of the Voronoi diagram in several ways. One way to extend Voronoi diagrams is to apply special weighting functions. Some examples of weighting can be found in the book by Okabe et al.(2000). One study applied both of these ideas in terms of generating Voronoi diagrams and Voronoiesque diagrams[1] for New York to generate districts (Svec et al., 2007). Svec et al. (2007) developed the Voronoi diagram using generator points placed at population centers. The districts are well distributed throughout the state or weighted by the largest peaks in the population distribution. In conclusion, this study helped to generate district boundaries that are simple, contiguous, and produce districts with equal populations.

Several authors have suggested that public facilities should combine both equity and efficiency for an optimal location or allocation. Iamtrakul et al. (2003) proposed a study of public park location using Voronoi diagrams to measure the equity of access to public park services. By considering the transportation network, public transport and pedestrian accessibility as main indicators and employing Voronoi diagrams, the size of existing park are incorporated and a suitable location for a new park is recommended. Another Voronoi diagram application is given by Karimi et al. (2009), who propose ordinary and multiplicatively weighted Voronoi diagrams to allocate students to the closest possible public school in Tehran, Iran. An ordinary Voronoi diagram is used to create school service areas

[1] Voronoiesque diagrams are used to create regions as a modification of the intuitive construction of Voronoi diagrams. Voronoiesque diagrams grow the shapes radially outward at a constant rate from each generator points. These shapes are circles in the Euclidean metric, diamonds in the Manhattan metric and squares in the Uniform metric. The interior of these shapes form the regions of the diagram. When the regions intersect they form the boundary lines.

that allocate students to the closest possible public schools, while the multiplicatively weighted Voronoi diagram uses the size of schools as weights.

The previous studies of Voronoi diagrams provide simple and appealing solutions for many problems from a wide variety of disciplines. In the light of the literature, we are applying Voronoi diagrams to improve geographic equity in our acute care hospital bed allocation problem.

CHAPTER 3

Methodology

The methodology presented in this chapter includes both a step by step description of the current method of bed allocation used by the Division of Health Service Regulation in preparing the SMFP, and a more detailed description of how Voronoi diagrams, and the nearest search problem are used to create service areas for acute care hospitals in the proposed methodology. This section also includes a review of the basic properties of Voronoi diagrams to present the concept more comprehensively.

3.1. Current Method

This section presents the acute care bed calculation currently used in the State Medical Facilities Plan introduced by North Carolina Division of Health Service Regulation.

The basic assumptions of the current methodology are as follows:

- Efficiency of operation should be encouraged by target occupancies that vary with average daily census:

Table 3.1: Average Daily Census vs. Target Occupancy of Licensed Acute Care Beds

Average Daily Census	Target occupancy of Licensed Acute Care Beds
1-99	66.7%
100-200	71.4%
Greater than 200	75.2%

- To determine utilization and average daily census, only acute care bed “days of care” are counted.

- If a hospital has received an approval for increasing or decreasing its acute care bed capacity, this change is incorporated into the anticipated bed capacity regardless of the licensure status of the beds.

3.1.1. Application of the Current Methodology

Under the current approach, the service area of an acute care bed is a single county unless there is no hospital located within that county. Counties lacking a licensed acute care hospital are grouped with either one or two counties that have at least one licensed acute care hospital. According to the 2010 SMFP, there are 114 acute care hospitals in North Carolina, as shown in Figure 3.1.

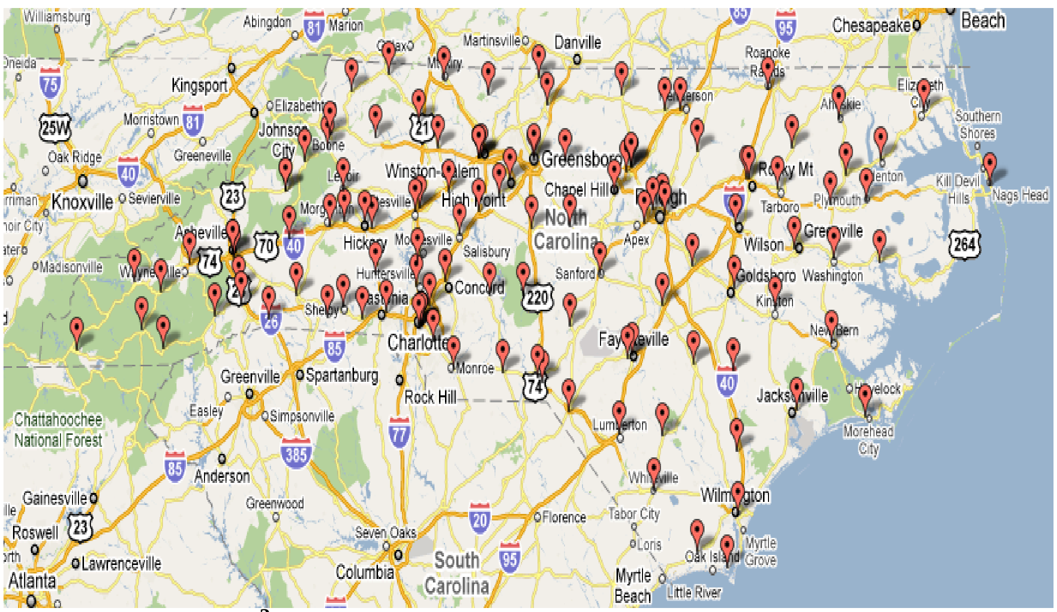

Figure 3.1: Map[2] for the Acute Care Hospitals in North Carolina

[2] The map is created using the website batchgeo.com

The current methodology is presented step by step in this section. All steps can be followed in the columns of the table represented in Appendix A as the Acute Care Bed Need Projections, which illustrates the calculations used to determine bed needs.

Step i) The Hospital License Number, Hospital Name, County, Licensed Beds and Adjustments information are given in Appendix A, and the Acute Care Bed Need Projections published in the State Medical Facilities Plan are listed in the appropriately headed columns. The county totals for Licensed Beds and Adjustments are updated by summing these values.

Step ii) The number of bed days used in 2008 is given in the appropriately headed column. The county total of 2008 Bed Census Days for counties with multiple hospitals is also given under this column.

Step iii) The state's annual population growth rate is calculated as follows for a given year *i*:

d_i: *Number of Acute Care Inpatient Days*

r_i: *Annual Growth Rate of i^{th} year*

$$r_i = \frac{d_i - d_{i-1}}{d_i}$$

To determine the average annual historical percentage change for the State, a three-year moving average is used as follows:

$$3year\ Average\ Growth\ Rate_{i+2} = \frac{r_i + r_{i+1} + r_{i+2}}{3}$$

Table 3.2: 3-year Average Growth Rate (SMFP)

Year	Days	Annual Growth Rate		3-year Average Growth Rate	
1996	4,373,602				
1997	4,344,434	-0.67%			
1998	4,342,032	-0.06%		0.52%	97-99
1999	4,305,125	-0.85%		0.61%	98-00
2000	4,423,151	2.74%		1.01%	99-01
2001	4,472,918	1.13%		1.35%	00-02
2002	4,480,926	0.18%		1.15%	01-03
2003	4,576,550	2.13%		1.52%	02-04
2004	4,679,727	2.25%		1.58%	03-05
2005	4,695,848	0.34%		0.47%	04-06
2006	4,639,819	-1.19%		0.01%	05-07
2007	4,680,021	0.87%		**0.02%**	06-08
2008	4,698,342	0.39%			

According to this calculation, the 3-year average population growth rate for 2008, which is used for the 2010 State Medical Facilities Plan, is 0.02%.

Step iv) The predicted growth in annual bed usage over the next 6 years for each hospital is predicted using the 3-year average growth rate as follows:

$$Hospital\ 6Yr\ Predicted\ Annual\ Bed\ Usage$$

$$= (2008\ Bed\ Census\ Days) * (1 + 3year\ Average\ Growth\ Rate)^6$$

The average daily number of beds in use in six years is then estimated as;

$$Predicted\ 6Yr\ Daily\ Beds\ in\ Use = \frac{Hospital\ 6Yr\ Predicted\ Anuual\ Bed\ Usage}{365}$$

Step v) The hospital's Occupancy Adjusted Beds are calculated as follows:

Table 3.3: Calculation of Hospital's Occupancy Adjusted Beds

6Yr Predicted Daily Census	Occupancy Adjusted Beds
<100	(6Yr Predicted Daily Census) * 1.55
≥101 and ≤200	(6Yr Predicted Daily Census) * 1.4
>201	(6Yr Predicted Daily Census) * 1.33

Step vi) The hospital's deficit or surplus is calculated as

Deficit = max { 0, -(Occupancy Adjusted Beds – (Licensed Beds + Adjustments)}.

Surplus = max{ 0, (Occupancy Adjusted Beds – (Licensed Beds + Adjustments)}.

Step vii) Finally:

If either *(Deficit or Surplus > 20)* or *(Deficit or Surplus ≥ 0.1*(Licensed Beds + Adjustments)), Need Determination = Deficit or Surplus*; otherwise, *Need Determination = 0.*

3.2. Proposed Method

Our proposed method calculates the number of acute care beds provided by each hospital and the number of acute care days expected for each hospital considering geographic equity. This is done using a Voronoi diagram using the acute care hospitals in North Carolina as the generating points. The proposed method also considers the estimated population in each Voronoi polygon to calculate the acute care bed needs for each hospital.

Before explaining the proposed model further, a more detailed description of Voronoi diagrams, the history of the concept of the Voronoi diagram, and some mathematical preliminaries need to be presented.

3.2.1. Introduction to Voronoi Diagrams

A Voronoi diagram is the partitioning of a plane with *n* points into convex polygons. Each polygon contains exactly one generating point and every point in a given polygon is closer to its generating point than to any other. For ease of exposition of Voronoi diagrams in the real plane R^2, we will explain them using Figure 3.2. The six bold points in this figure represent a set of given points given in the Euclidean plane. The number of points should be at least two and finite. In Figure 3.2, every location in the plane is assigned to the closest in the point set. If a location happens to be equally close to two or more points of the point set, we assign that location to both points (In Figure 3.2, p' is equally close to p_1 and p_3, so, p' is assigned to these points.)

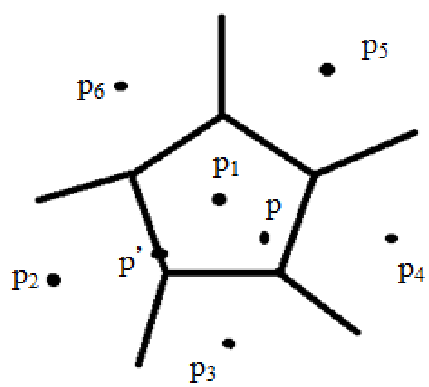

Figure 3.2: A planar ordinary Voronoi diagram

Hence the set of locations assigned to each member in the point set forms its own region (In Figure 2.1, the pentagonal region is one such region).

When we associate each point in the Euclidean plane with the closest generating point with respect to the Euclidean distance, the result will be a tessellation (partition) of that plane into a number of regions each associated with a generating point. This tessellation is called the planar ordinary Voronoi diagram generated by the point set, and the regions created by that Voronoi diagram ordinary Voronoi diagram polygons. In general, a planar ordinary Voronoi diagram is referred to as a Voronoi diagram while an ordinary Voronoi polygon is referred to as a Voronoi polygon.

In order to restate this definition mathematically, let us consider a set of $2 < n < \infty$ generating points p_i, $1 \leq i \leq n$ in the Euclidean plane with associated coordinates (x_i, y_i). Let p denote an arbitrary point in the Euclidean plane with coordinates (x,y). The Euclidean distance between the arbitrary point p and generating point p_i is given by:

$$d(p, p_i) = \left||x - x_i|\right| = \sqrt{(x_1 - x_{i1})^2 + (x_2 - x_{i2})^2}$$

If p_i is the nearest or one of the nearest point to p (the relationship between p_1 and p in Figure 2.1), the relation is;

$$\left||x - x_i|\right| \leq \left||x - x_j|\right| for\ all\ j \neq i$$

So, p is assigned to p_i and the Voronoi region associated with p_i is given by;

$$V(p_i) = \{x| \left||x - x_i|\right| \leq \left||x - x_j|\right|\ for\ j \neq i\ j\epsilon I_n$$

The set of Voronoi polygons associated with the set of generator points p_i is given by;

$$\mathcal{V} = \{V(p_1), \dots, V(p_n)\}$$

The Voronoi diagrams drawn for the acute care hospitals in North Carolina are presented in Chapter 4 as results.

3.2.1.2 Basic Properties of Voronoi Diagrams for $\mathbb{R}^2$

There are some concepts which need to be presented before the properties.

Delaunay Triangulation: In computational geometry, a Delaunay triangulation for a set P of points in the plane is a triangulation *DT(P)*. There should be no points in P which lie inside the circumcircle of any triangle in *DT(P)*. Delaunay triangulations tend to avoid skinny triangles, so they maximize the minimum angle of all the angles of the triangles in the triangulation. The Delaunay triangulation of the point set P is equivalent to the dual graph of the Voronoi tessellation.

Convex hull: The convex hull is typically represented by a sequence of the vertices of the line segments forming the boundary of the polygon.

There are seven types of Voronoi diagrams (i.e., the ordinary Voronoi diagram, the farthest-point Voronoi diagram, the weighted Voronoi diagram, the network Voronoi diagram, the Voronoi diagram with a convex distance function, the line Voronoi diagram, the area Voronoi diagram). The properties given below are for an ordinary Voronoi diagram since this is the primary focus of this research.

Property 1:

Let $P = \{p_1, \dots, p_n\} \subset \mathbb{R}^2$ $(2 \leq n < \infty)$ be a set of distinct points. The set $V(p_i)$ is defined by

$$V(p_i) = \{x \mid \left||x - x_i|\right| \leq \left||x - x_j|\right| \; for\ i \neq j\ i, j \epsilon I_n$$

This is a non-empty polygon, and $\mathcal{V} = \{V(p_1), \dots, V(p_n)\}$ satisfies $\bigcup_{i=1}^{n} V(p_i) = \mathbb{R}^2$, and

$$[V(p_i)\backslash \delta V(p_i)] \cap [V(p_j)\backslash \delta V(p_j)] = \emptyset, i \neq j\ i, j \epsilon I_n$$

$\mathcal{V}(P)$ is a unique tessellation of $\mathbb{R}^2$ for P.

Property 2:

If a Voronoi diagram is generated by $P = \{p_1, \dots, p_n\} \subset \mathbb{R}^2 (2 \leq n < \infty)$, a Voronoi polygon $V(p_i)$ is unbounded if and only if p_i is on the boundary of the convex hull of P.

Property 3:

For a Voronoi diagram generated by $P = \{p_1, \dots, p_n\} \subset \mathbb{R}^2 (2 \leq n < \infty)$;

(a) If P is collinear, the Voronoi edges are infinite straight lines.

(b) If P is noncollinear and p_i and p_j are consecutive generator points of the boundary of the convex hull of P, a Voronoi edge is a half line.

(c) If p_i and p_j gives a Voronoi edge and if and only if the line segment of $p_i p_j$ is not an edge of the convex hull of P, this edge is a finite line segment.

Property 4:

The nearest generator point of p_i generates a Voronoi edge of $V(p_i)$.

Property 5:

The nearest generator point from p_i exists in the generator points. The Voronoi polygons of these points share the Voronoi edges of $V(p_i)$. This property is useful in solving the closest pair problem and the all neighbor problem.

Property 6:

The generator point p_i is the nearest generator point from the arbitrary point p if and only if $V(p_i)$ contains p.

Property 7:

For every Voronoi vertex in a Voronoi diagram, there exists a unique circle centered at this vertex. This circle passes through three or more generator points and contains no points in its interior. This circle passes through three generator points under the nondegeneracy assumption.

Property 8:

The circle mentioned in Property 7 is the largest empty circle among all empty circles centered at the Voronoi vertex $q_{i,} q_i \in Q$. This property with a slight modification is useful in solving the largest empty circle problem.

Property 9:

Let n denote the number of generator points ($2 \leq n < \infty$), n_e the number of Voronoi edges, and n_v the number of Voronoi vertices in $\mathbb{R}^2$. Then;

$$n_v - n_e + n = 1$$

3.2.2. Calculation of Voronoi Population

The basis of our proposed approach is to use a Voronoi diagram to estimate the population that is geographically closest to each healthcare facility hospital, and hence is likely to seek healthcare at that facility. To accomplish this, we first compute the Voronoi diagram generated by the existing facilities. This Voronoi diagram identifies geographic regions such that the facility located at the generating point of the region is the closest facility to all residents of that region. We use GIS data to identify the census tracts that lie fully or partially within each region, and then use census data on the populations of these census tracts to estimate the population of each Voronoi region, assuming the population of a census tract is uniformly distributed over its area. The population of a census tract that is shared by multiple Voronoi regions is allocated based on the area of each census tract falling in each of the Voronoi regions. The population of the Voronoi region of each facility is thus an estimate of the population to be served by that facility, which we shall refer to as its *Voronoi population*.

Let P_i denote the set of points in the Euclidean plane lying in the Voronoi polygon associated with facility i, and C_j the set of points lying in the j^{th} census tract. Define the set of census tracts contributing to the population of P_i as

$$G_i = \{m \mid P_i \bigcap C_m \neq \emptyset\}$$

Let $A(K)$ denote the area of the region K in the Euclidean plane. The population of the i^{th} Voronoi polygon, i.e., the estimated population to be served by the i^{th} facility is then given by

$$\Pi(P_i) = \sum_{j=1}^{J} \Pi(C_j) \left(\frac{A(Pi \cap Cj)}{A(Cj)}\right)$$

We now apply our approach to the problem of estimating service areas for acute care hospitals in the State of North Carolina.

At this point, we also want to emphasize an issue related to the calculation of population. As we mentioned in the previous section, there might be open Voronoi polygons when there is no other generating point lying outside those given generating points. In our cases, the open polygons are formed around areas close to the borders of the State of North Carolina. In this case, we assign extra points for each open Voronoi polygon manually, which can make them close polygons and permits the calculation of the area of intersection between these polygons and census tracts. After that, we apply the same steps as we do for the close Voronoi polygons to calculate the population in each polygon lying close to the borders of the state

CHAPTER 4

Applications

4.1. Application of Voronoi Diagrams for Acute Care Hospitals in North Carolina

As mentioned in Chapter 3, there are 114 acute care hospitals in North Carolina. To construct the Voronoi diagram of the acute care hospitals in North Carolina, we first need to know the spatial location of the acute care hospitals. Since we draw the Voronoi diagram in Euclidean space, we convert the addresses of these hospitals obtained from 2008 Hospital License Renewal Data, published every year by the NC Division of Health Service Regulation, Medical Facilities Planning section, into longitude-latitude coordinates. Using these coordinates we draw the Voronoi diagram using the `voronoi(x,y)` function in Matlab R2009b, which plots the bounded cells of the Voronoi diagram for the points representing the coordinates of each hospital. The Voronoi diagram is presented in Figure 4.1. The red plus signs represent the acute care hospitals in North Carolina, the blue net-like lines define the Voronoi polygons for each hospital, and the green continuous line is the border of the state. The data source for the state borders is the Matlog map-data created by Dr. Michael Kay of the Edward P. Fitts Department of Industrial and Systems Engineering, North Carolina State University. The North Carolina State border in Matlog, in turn, obtains its data from World Data Bank II (1:2,000,000; N 53.61 S 14.9 W -125 E -65) of the Coastline Extractor created by Rich Signell of US Geological Survey and hosted by NOAA/National Geophysical Data Center, Marine Geology & Geophysics Division). The Voronoi polygon for each hospital defines the area such that the points in that region are closer to that acute care hospital than to any other hospital.

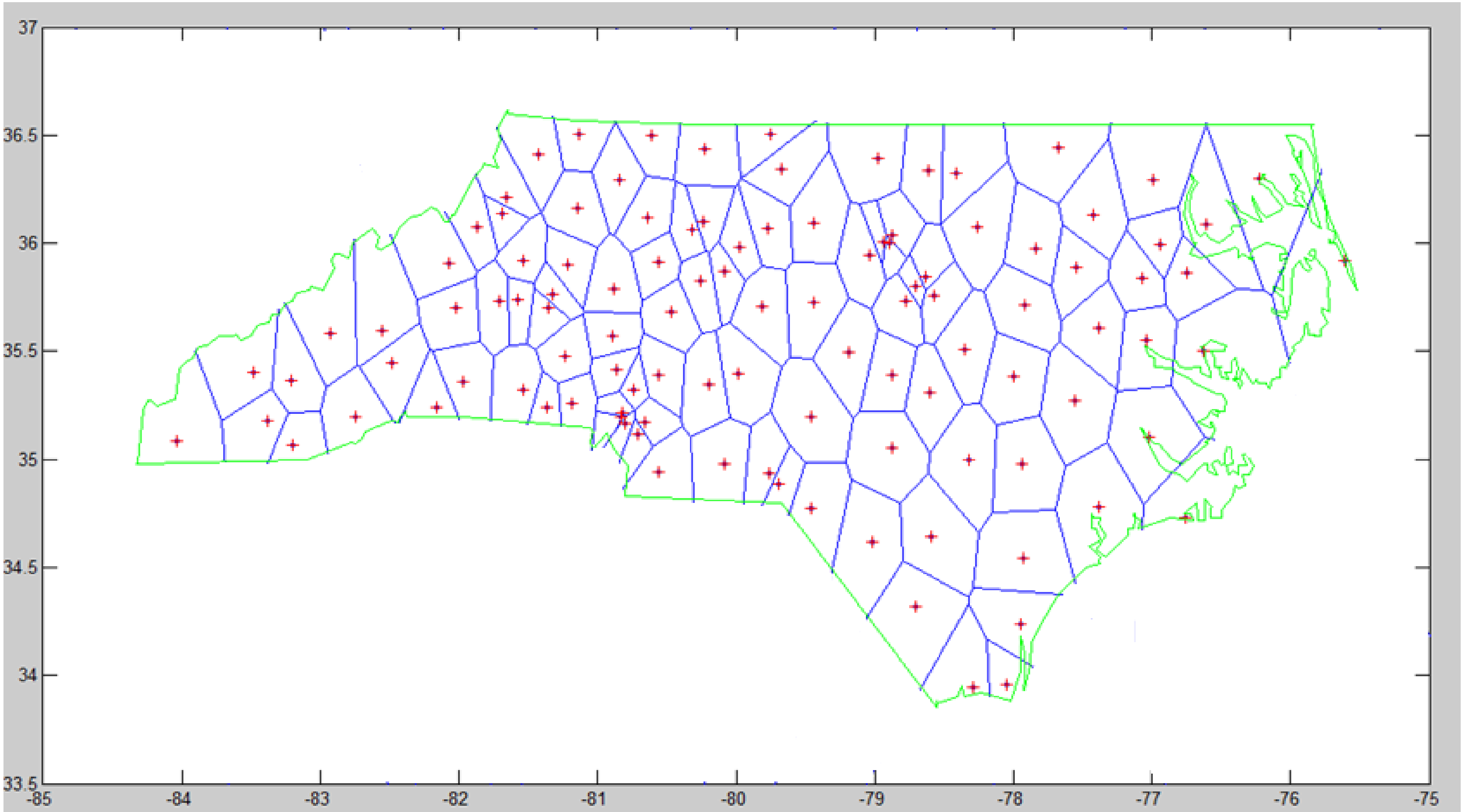

Figure 4.1: Voronoi Diagram for the Acute Care Hospitals with the Borders of North Carolina

Figure 4.2 represents the counties of North Carolina. Borders of each county are determined by a different color. There are 100 counties in North Carolina, and the required data, namely longitude and latitude data of the borders, is obtained from United States Department of Commerce, Bureau of the Census. This data was processed by deleting some points at the beginning and at the end of the data set created for each county to make it convenient for use in the `plot` function in Matlab.

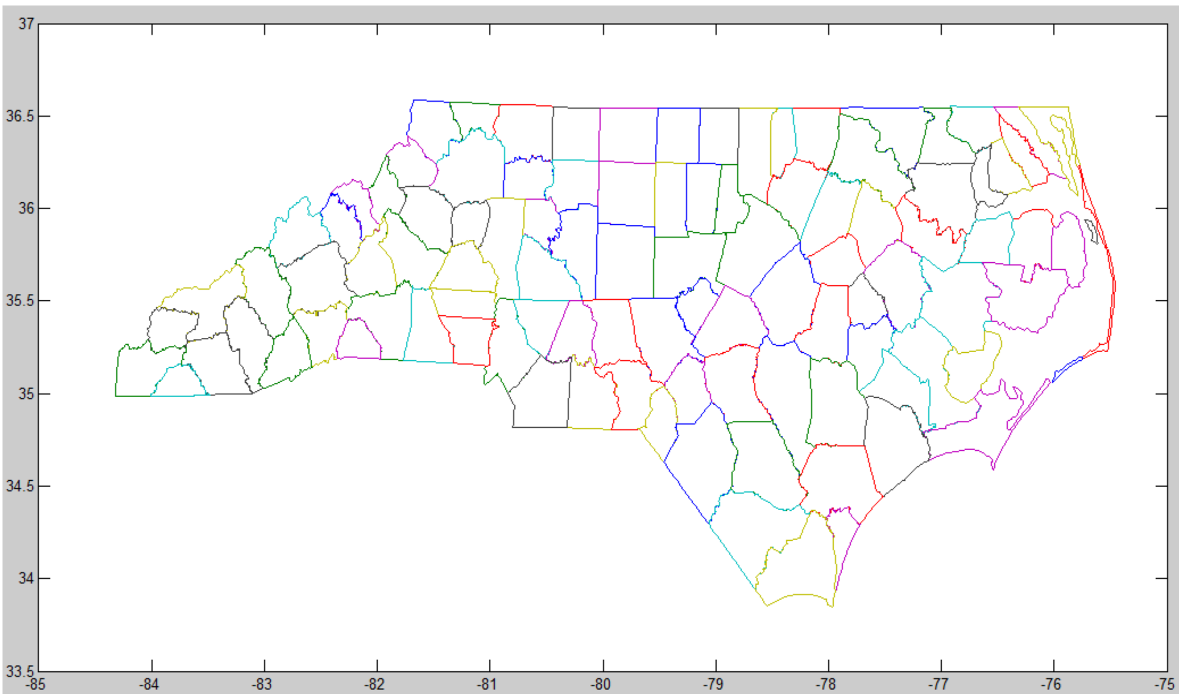

Figure 4.2: Counties of North Carolina

After creating the Voronoi diagram, we overlay it onto the map of North Carolina with county borders as shown in Figure 4.3.

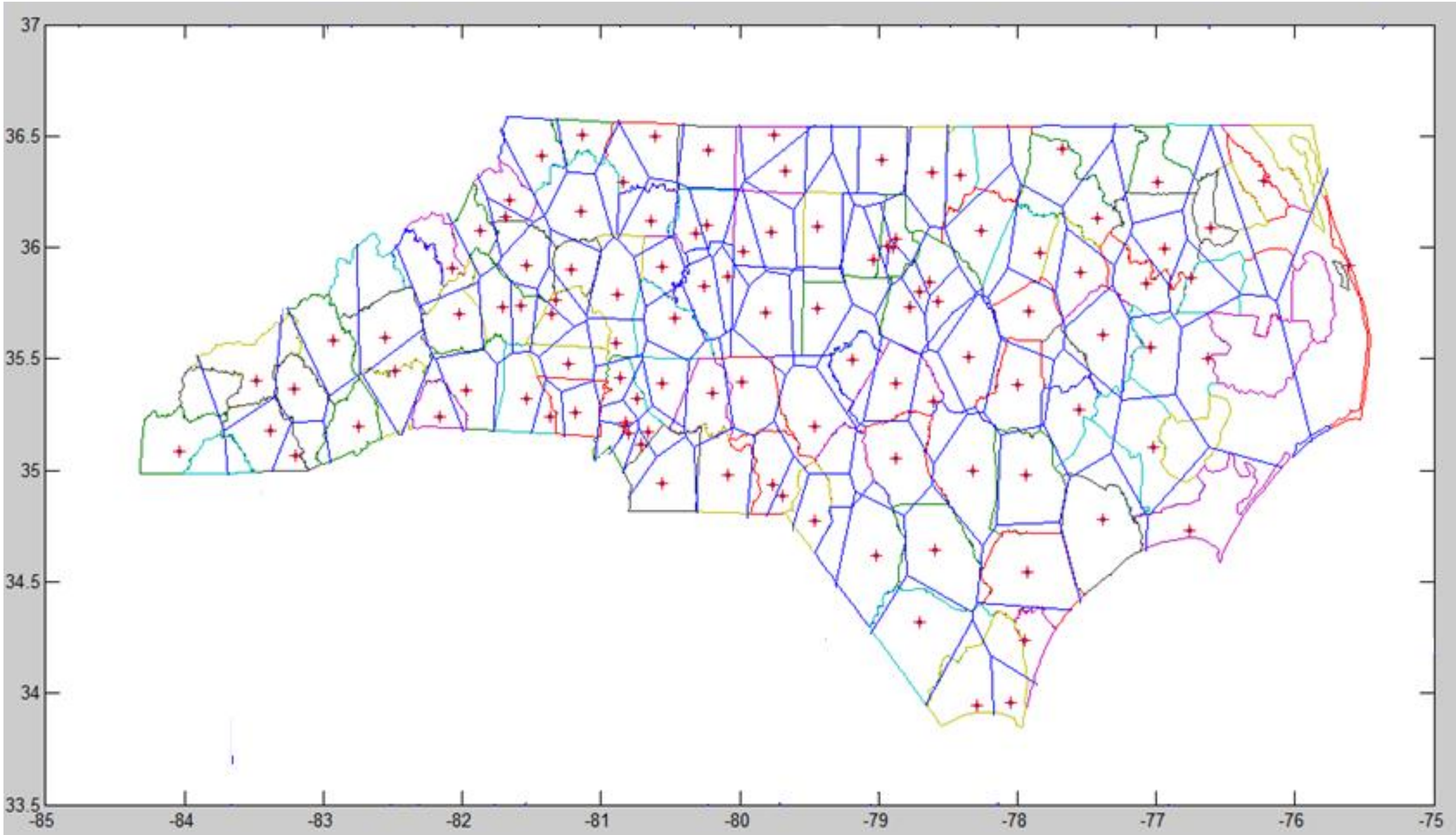

Figure 4.3: Voronoi Diagram for the Acute Care Hospitals with the County Borders of North Carolina

Figure 4.3 shows the relation between the counties and the Voronoi polygons created for each acute care hospital. On this figure, plus signs represent the acute care hospitals, blue lines are the vertices of Voronoi polygons, and polygons in different colors represent the borders of counties. Although the diagram is created mathematically, it fits surprisingly well with the borders of the counties, which were created politically. One cannot expect an exact fit since there are counties that include only one acute care hospital such as Alamance Regional Medical Center in Alamance County, counties with multiple acute care hospitals like Duke Health Raleigh Hospital, Rex Hospital, WakeMed Cary Hospital, WakeMed Raleigh Campus in Wake County, and counties without any acute care hospital such as Madison County. There are 114 acute care hospitals for 83 counties, and there are 17 counties without Acute Care Hospitals. The map in Figure 4.4 shows that distribution.

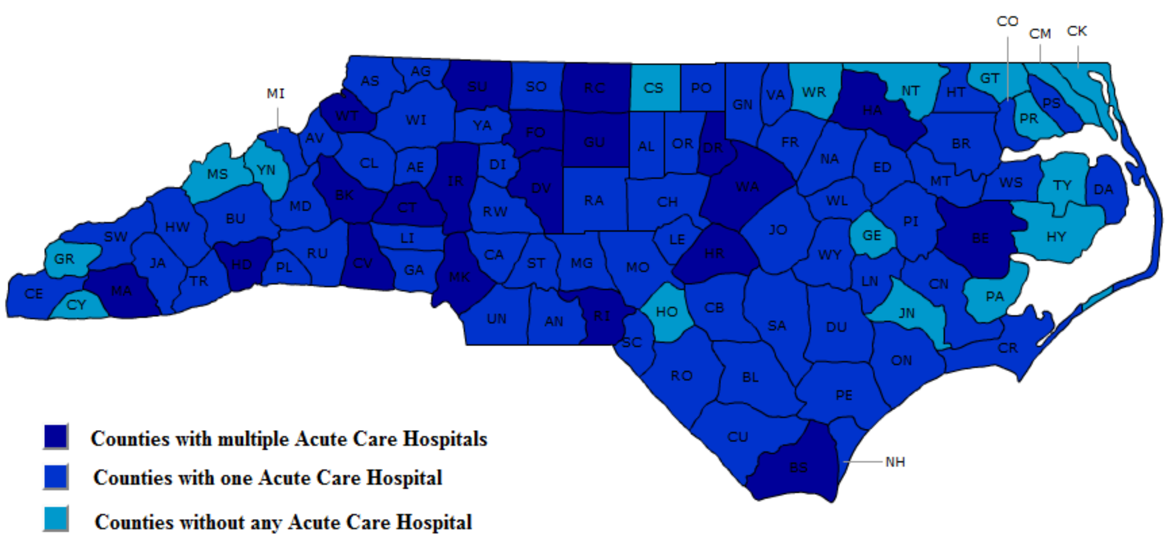

Figure 4.4: The distribution of acute Care Hospitals in North Carolina

In the coastal areas such as parts of Hyde, Dare, Carteret or Washington counties, calculation based on straight line distance can cause problems due to the fact that the closest facility by straight line distance may not in fact be closest by road.

At this point, in order to calculate the number of acute care beds for each acute care hospital according to the population in each Voronoi polygon, we decided to plot the census tracts in North Carolina onto the Voronoi diagram of the acute care hospitals in North Carolina presented in Figure 4.4. By definition of the Census Bureau, census tracts are small, relatively permanent geographic subdivisions of a county or equivalent entity. Figure 4.5 shows the census tract.

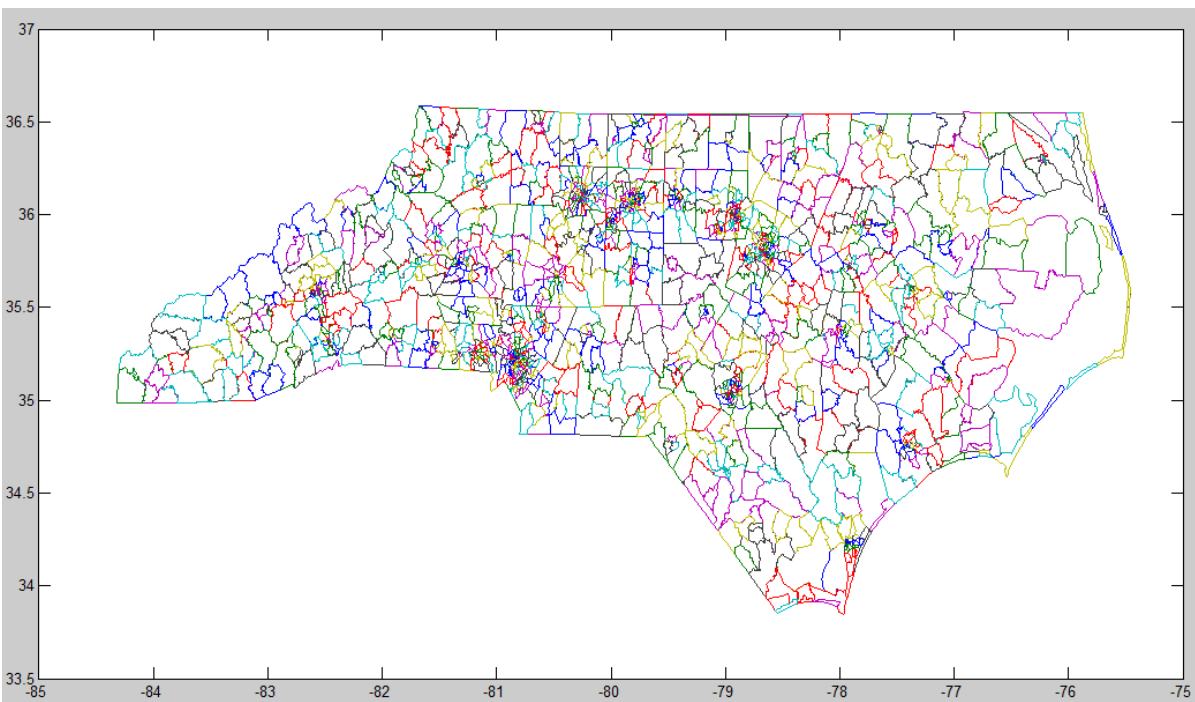

Figure 4.5: Census Tracts in North Carolina

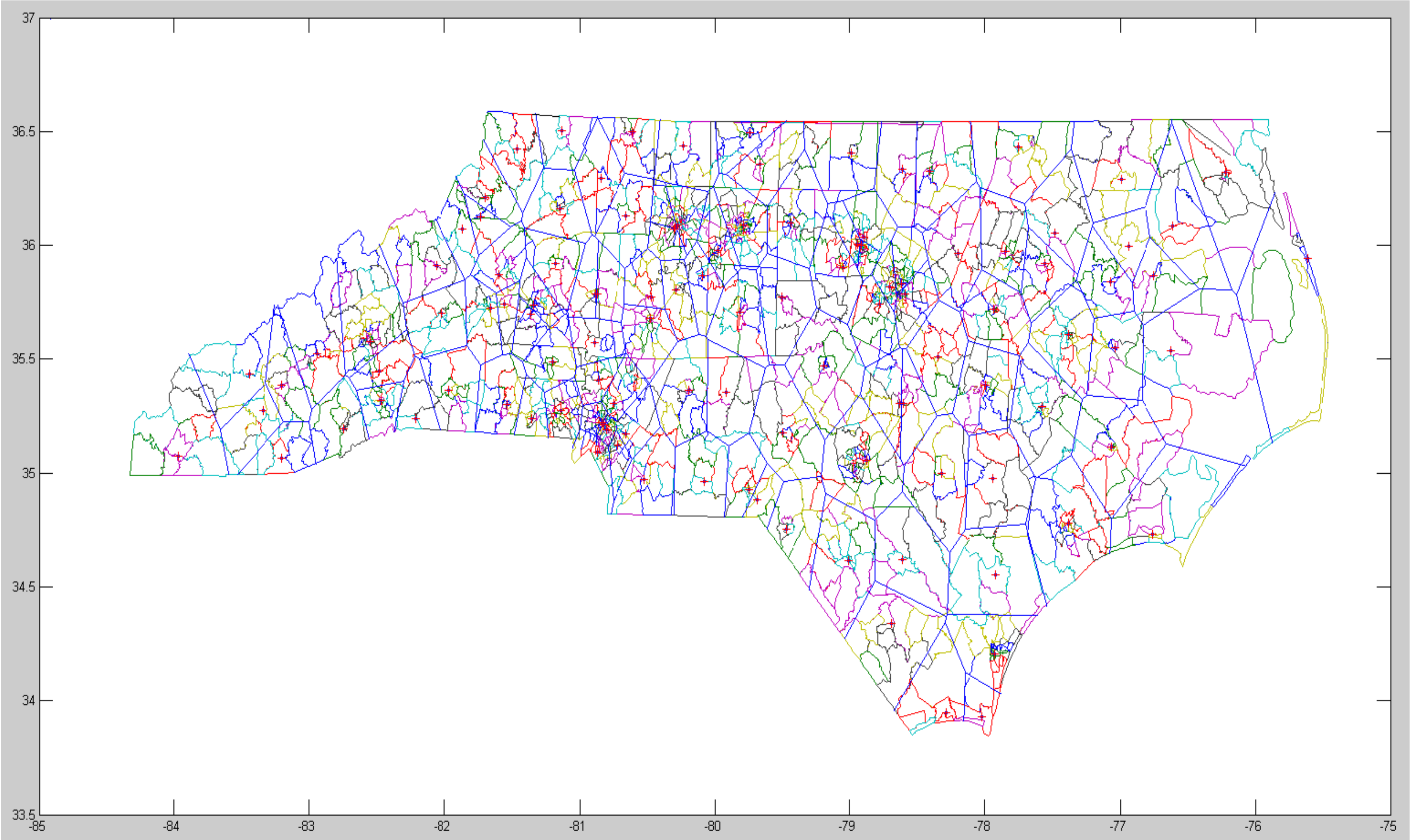

Figure 4.6: Voronoi Diagram for North Carolina Acute Care Hospitals with County Borders and Census Tracts

Figure 4.6 shows the Voronoi diagram plotted over the census tracts of North Carolina. We assume that the population of a census tract is uniformly distributed over its area, and we use GIS data to identify the census tracts that lie fully or partially within each region, and then use census data on the populations of these census tracts to estimate the population of each Voronoi region. The population of a census tract that is shared by multiple Voronoi regions is allocated based on the area of each census tract falling in each of the Voronoi regions. The population of the Voronoi region of each facility is thus an estimate of the population to be served by that facility, which we shall refer to as its *Voronoi population*. The population of each Voronoi polygon, and thus, the population assigned by our procedure to each hospital, is given in Appendix B.

The calculation of acute care beds and the number of beds determined by the population of each Voronoi polygon are given in Table under the Appendix B, The Acute Care Bed Need Projections according to Proposed Methodology in the appropriately headed columns. The data and definitions related to that data are given in Table 4.1.

Table 4.1: Data and Definitions for the Calculations of Proposed Model

Hospital	Names of acute care hospitals in North Carolina.
County	Names of the counties with acute care hospitals. The first 63 counties include only one acute care hospitals while another 20 counties include more than one acute care hospitals. There are 17 counties without any acute care hospital.
Voronoi Population	Population of each Voronoi polygon is represented on the 3rd column.
Number of Licensed Bed(w/o Adjustments)	Acute Care Days for each hospital presented by the State Medical Facilities Plan.
Adjustments	Adjustment for Certificate of Needs from previous year.
Number of Licensed Bed	Sum of the number of acute care beds and the adjustments for each hospital.

i) The Hospital License Number, Hospital Name, County, Licensed Beds, Adjustments, Licensed Beds with Adjustments, and the number of bed days used in 2008, which are obtained from the State Medical Facilities Plan are presented in the appropriately headed columns.

ii) The population of the Voronoi polygon (service area for each hospital) is also given in the appropriately headed column. The population is calculated by using the approach described above. Following this approach and using the codes, which are presented in Appendix G, created in Matlab, we assign each census tract to an acute care hospital, which is the closest to this census tract.

iii) To calculate the acute care days and the number of acute care beds according to the population of each Voronoi polygon (related population for each hospital), we first need to calculate the Acute Care Beds per Population and the Acute Care Beds per Acute Care Days to determine how to assign acute care beds to each hospital.

Recall that $\pi(P_i)$ denotes the estimated population to be served by the i^{th} acute care hospital, D_i the acute care days for i^{th} hospital and B_i the number of acute care beds for the i^{th} hospital. The acute care days per capita for North Carolina is calculated as follows;

$$C = \frac{\sum_{i=1}^{n} D_i}{\sum_{i=1}^{n} \pi(Pi)} = 0.565$$

The number of acute care beds per acute care day gives the number of acute care beds per acute care day used in North Carolina, and is calculated as follows;

$$A = \frac{\sum_{i=1}^{n} B_i}{\sum_{i=1}^{n} D_i}$$

yielding a value of 0.0046 for the time period 2010-2011.

iv) The computed acute care days is calculated as

$$Computed\ Acute\ Care\ Days = C * Voronoi\ Population.$$

v) Computed acute care beds for each hospital are obtained as

$$Computed\ Acute\ Care\ Beds = A * Computed\ Acute\ Care\ Days.$$

vi) Finally, the difference between the calculated number of acute care beds for each hospital and the number of licensed acute care beds is presented. If this difference is positive, then this number gives the acute care bed deficit for this hospital, otherwise it represents the acute care bed surplus for this hospital. If the difference is zero, then this hospital has neither surplus nor deficit in beds, which means that hospital already has sufficient capacity according to the proposed methodology. In other words, this hospital has already achieved geographic equity based on the current methodology.

Figure 4.9 and Figure 4.10 show the difference between the calculated number of acute care beds and the number of acute care beds. Figure 4.9 shows the deficit in acute care beds for each hospital while Figure 4.10 shows the surplus in acute care beds for each hospital according to our methodology.

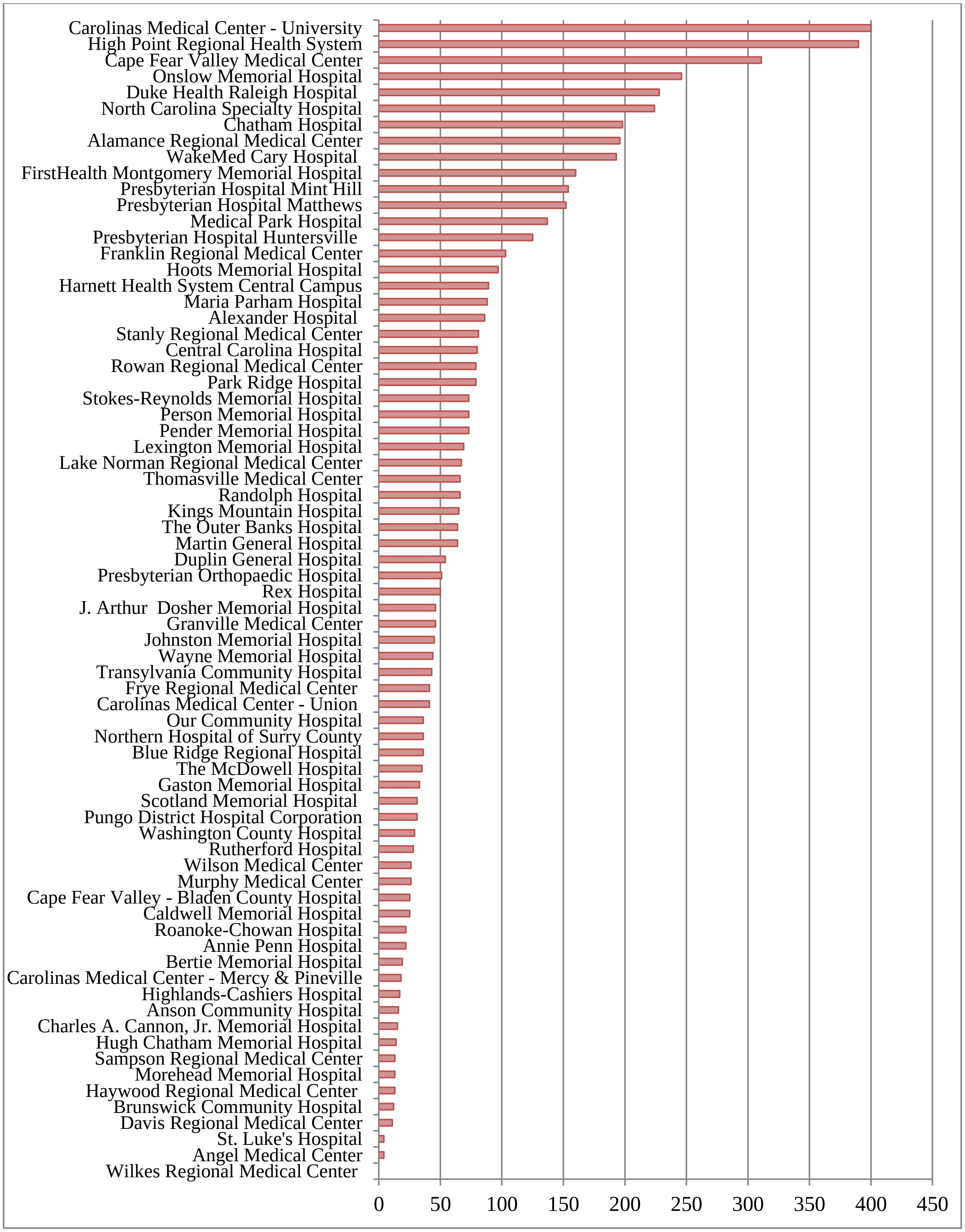

Figure 4.7: Deficit in Acute Care Bed for each Hospital according to Voronoi Approach

Figure 4.8: Surplus in Acute Care Bed for each Hospital according to Voronoi Approach

As presented in Figure 4.7., the Voronoi approach identifies 35 hospitals which need more than 50 additional beds, while the remaining 36 hospitals need fewer than 50 additional beds. The highest deficits between the proposed and current approaches are for Carolinas Medical Center-University. Carolinas Medical Center-University is in Cabarrus County, where there is an only one acute care hospital. It appears that because of the high population in Cabarrus and high population in its neighbor counties such as Mecklenburg, which has the highest population in North Carolina, Union, Iredell, Rowan, the population assigned to that hospital is high. Since the number of acute care beds is determined by the population in the service area of the hospital, the number of acute care bed days is found to be 105,544 days, compared to 66,324 according to the current methodology. We see the same result for High Point Regional Health System, whose deficit in beds is the second highest with 390 beds. The service area of this hospital obtained by the Voronoi diagram has the highest population of all service areas created by the Voronoi diagram. The effect of the population applies to the other hospitals in Figure 4.7.

Figure 4.8, which shows the surplus in beds according to Voronoi Approach, presents the hospitals whose current number of beds exceeds that obtained using the Voronoi approach. For most of these hospitals, the surplus is less than 100, but as seen in the Figure 4.8, the maximum surplus in beds with 730 beds is more than the maximum deficit in beds with 400 beds. Most of the hospitals with more than 300 surplus beds are tertiary care hospitals. These include Duke University Hospital, Forsyth Medical Center, Pitt County Memorial Hospital, and University of North Carolina Hospitals. Since the length of stay of patients in a tertiary care hospital is more complex than that for a regular acute care hospital, the number of acute care days is higher than that for a regular acute care hospital. As mentioned in Chapter 3, the number of beds calculation in the current methodology is done by multiplying the acute care days by growth rate and then finding the average daily census and adjusting it for target occupancy. In other words, the base data is the Thomson acute care days. For the proposed methodology, the base data is the population in the service area of each hospital. Additionally, there is data on acute care days of each hospital. To add the effect of the acute care days, we calculate a statewide acute care days per population and acute care beds per acute care days.

Table 4.2: Average Maximum Distance and Variance in Maximum Distance for Current Methodology and Proposed Methodology

	Proposed Voronoi Methodology	**Current SMFP Methodology**
Average Max Distance (miles)	**0.3072**	**0.5995**
Variance in Max Distance (miles)	0.0120	0.6681

As seen from these maps and Table 4.2, the average of the maximum distance to the acute care bed in the service area of its related acute care hospital is less in the proposed Voronoi methodology than for current SMFP methodology. That shows us the average maximum distance that a patient should take to be served by the closest hospital is lower than the average maximum distance that a patient should take to be served by the hospital in the county that he/she resides in. The distances are given in miles and calculated as Euclidean distances. The maximum distances for each hospital according to the proposed Voronoi methodology and those according to current SMFP are given in Appendix C As pointed out before, there are counties without any hospital or counties with more than one hospital. For calculation of the maximum distance in a county with one acute care hospital, we use the same method with the calculation of the maximum distance in a service area (Voronoi polygon). The SMFP assigned the counties without any hospital to one of its neighbor counties which are served by at least one hospital. Thus, we merge the counties without any hospital with those assigned to a hospital by SMFP, and we calculate the maximum distance to access the acute care hospital accordingly. For counties with more than two hospitals, we use Voronoi diagrams to create areas from the points that are closer to the hospital than to any other hospitals in that county, and calculate the maximum distances for each hospital in that county individually. Finally, for the counties with two hospitals, we draw a line between them to assign those areas as their service areas and calculate the maximum distances accordingly. Table 3 also includes the variance in maximum distance in each service area, which shows that Voronoi diagram methodology provides a significantly more balanced result in terms of comparing the maximum distances in each service area.

The maps created for both acute care days and acute care beds for each county by both calculations according to the current and proposed methodologies are given below in Figures 4.9, Figure 4.10, Figure 4.11, and Figure 4.12.

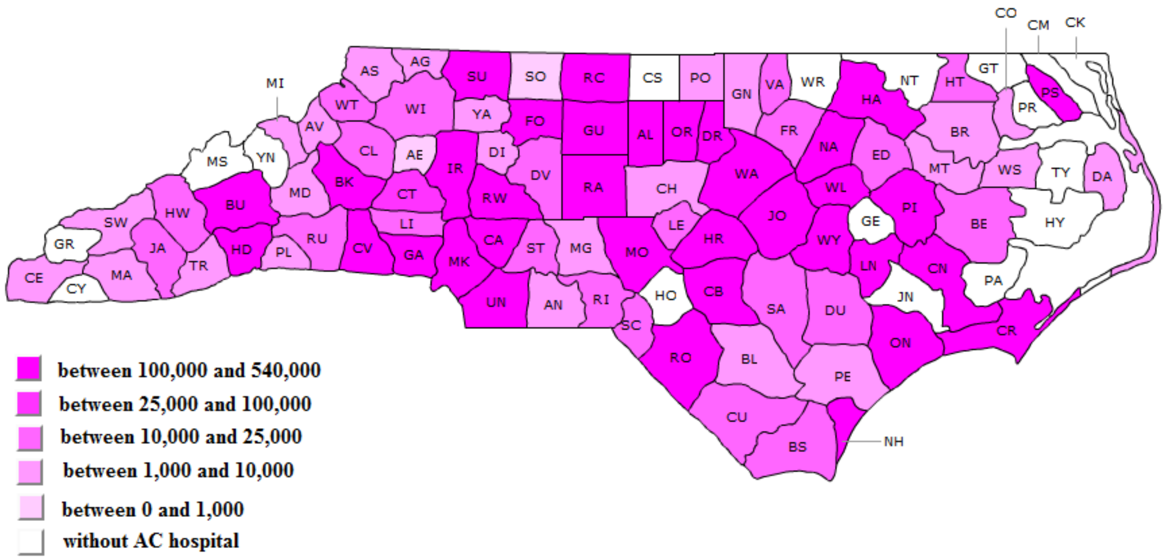

Figure 4.9: Acute Care Days for each County according to Current (SMFP) Methodology

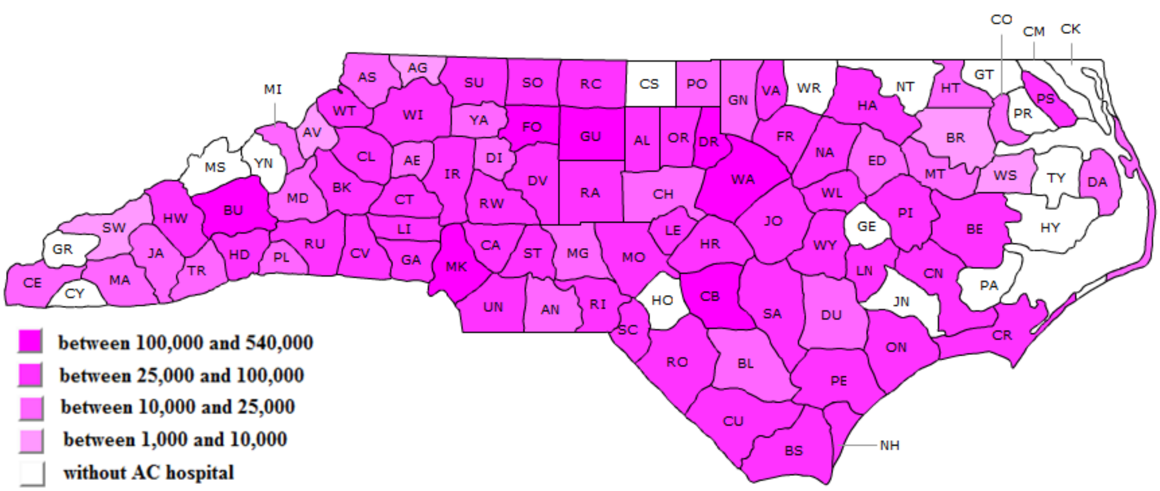

Figure 4.10: Acute Care Days for each County according to Proposed Methodology

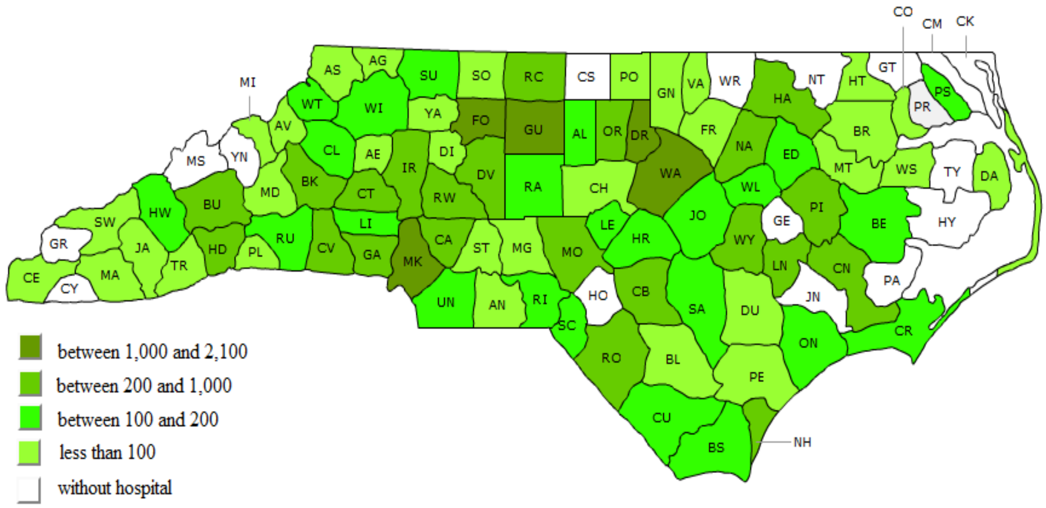

Figure 4.11: Acute Care Beds for each County according to Current (SMFP) Methodology

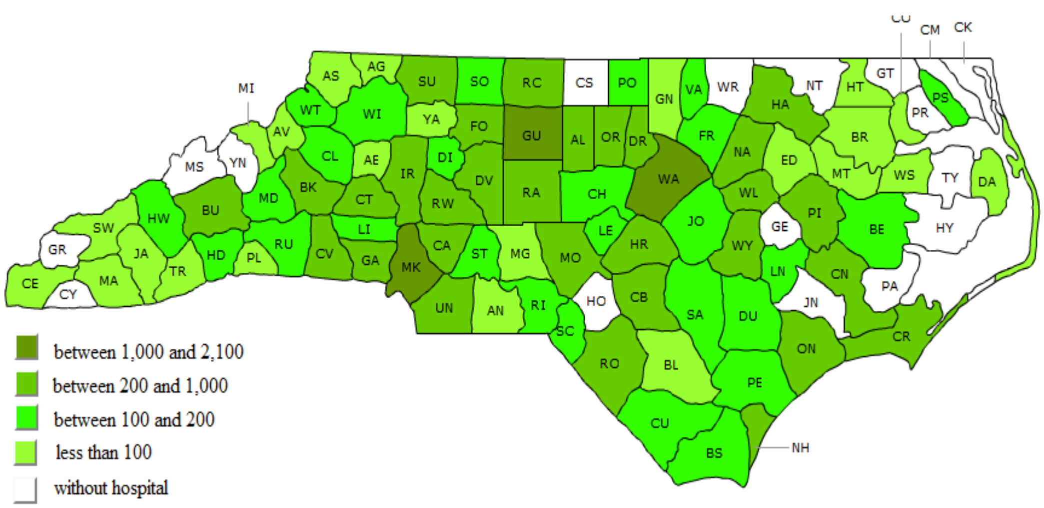

Figure 4.12: Acute Care Days for each County according to Proposed Methodology

After excluding the four tertiary care facilities with large acute care bed capacity and the most acute care inpatient days, (Those are University of North Carolina Hospitals, Pitt

County Memorial Hospital, Duke University Hospital, and Forsyth Medical Center), the Voronoi diagram is found as shown in Figure 4.13. Figure 4.14 shows the Voronoi diagram with the county borders of North Carolina as done previously for the Voronoi diagram for all the acute care hospitals in North Carolina. Lastly, to calculate the number of acute care beds and the acute care days by the effect of population, we plot the center point of the census tracts as shown in Figure 4.15. The population of each Voronoi polygon is calculated under the same assumptions used for the previous calculation. After going through all the steps explained for the calculation for all the acute care hospitals, the table shown in the Appendix D is created.

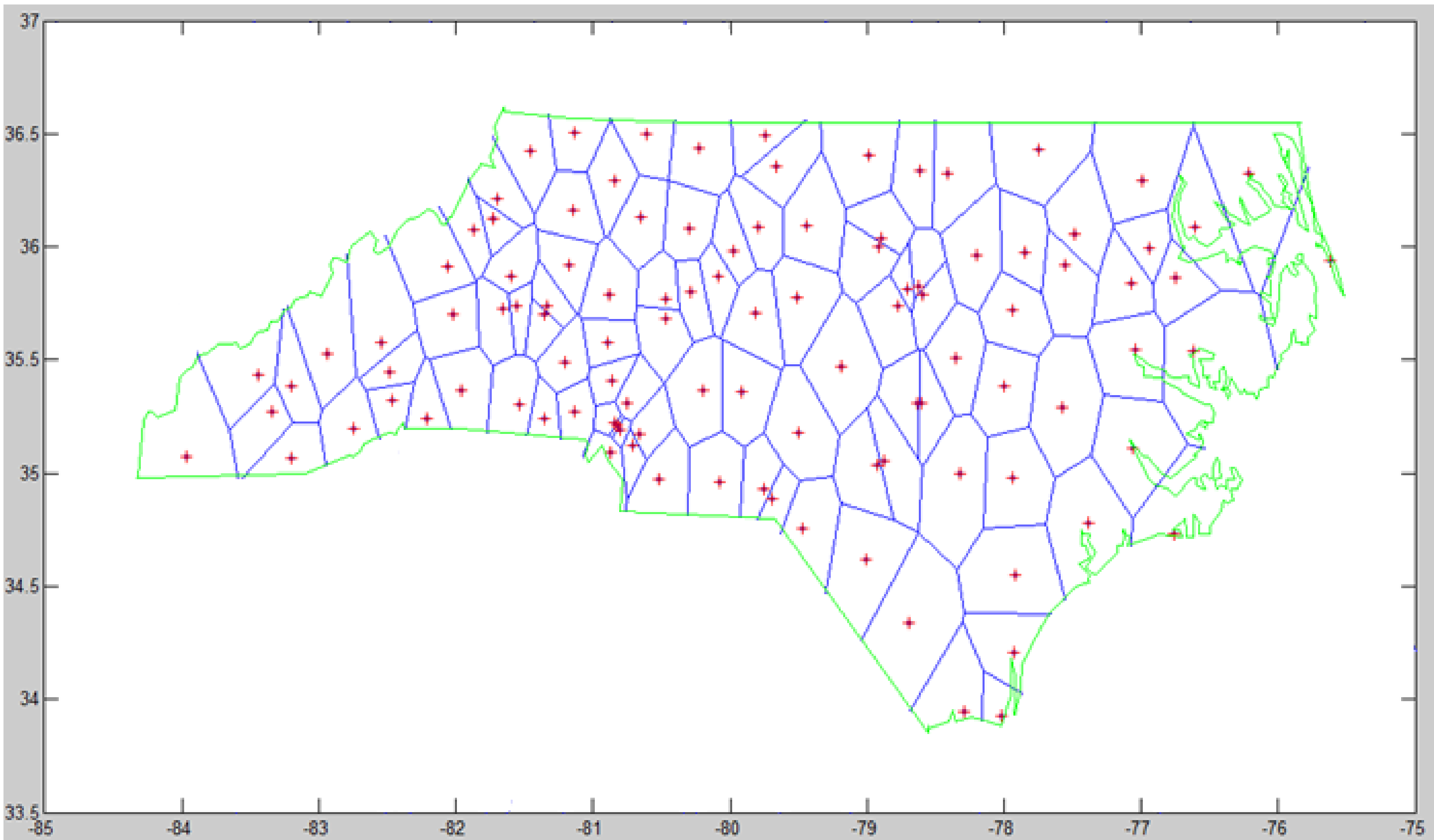

Figure 4.13: Voronoi Diagram for the Acute Care Hospitals with the Borders of North Carolina ***(University of North Carolina Hospitals, Pitt County Memorial Hospital, Duke University Hospital, North Carolina Baptist Hospitals excluded)***

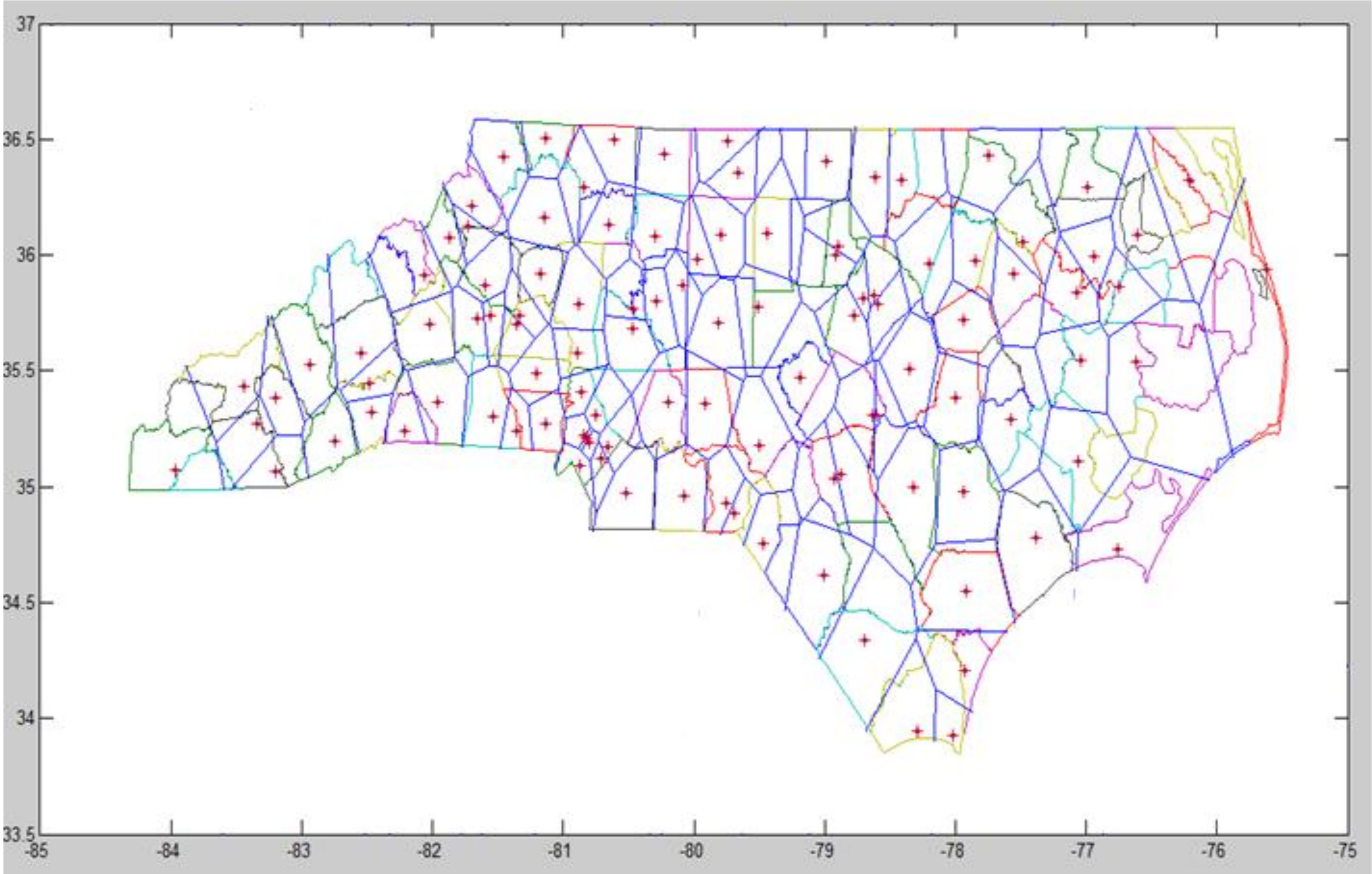

Figure 4.14: Voronoi Diagram for the Acute Care Hospitals with the County Borders *(University of North Carolina Hospitals, Pitt County Memorial Hospital, Duke University Hospital, North Carolina Baptist Hospitals excluded)*

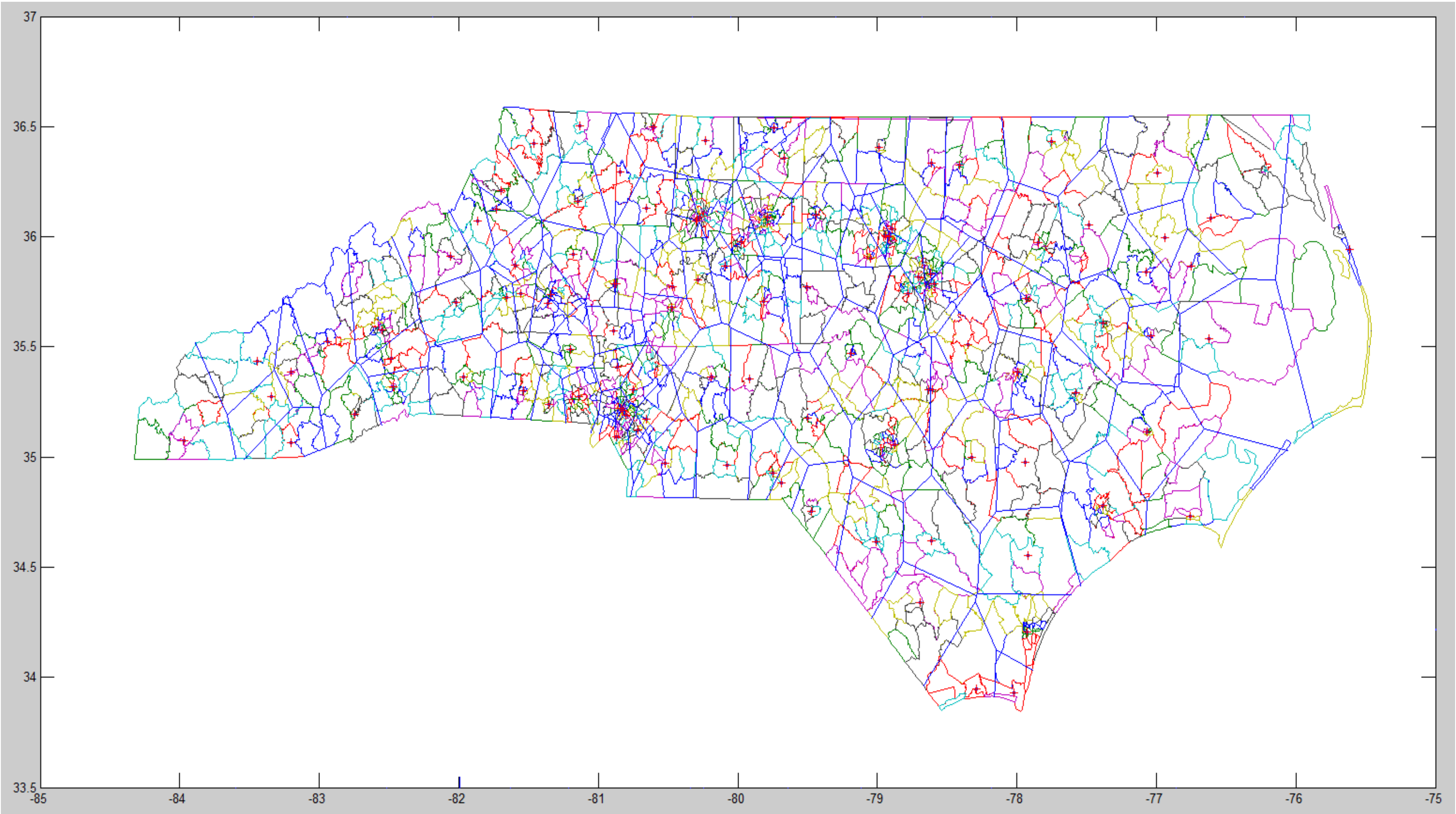

Figure 4.15: Voronoi Diagram for the Acute Care Hospitals with the County Borders and Census Tracts of North Carolina ***(University of North Carolina Hospitals, Pitt County Memorial Hospital, Duke University Hospital, North Carolina Baptist Hospitals excluded)***

Figure 4.16 shows the Voronoi diagrams for the acute care hospitals including the tertiary care hospitals plotted on the Voronoi diagram for the acute care hospitals excluding the tertiary care hospitals. The only differences between the Voronoi diagrams arise around the proposed tertiary care hospitals.

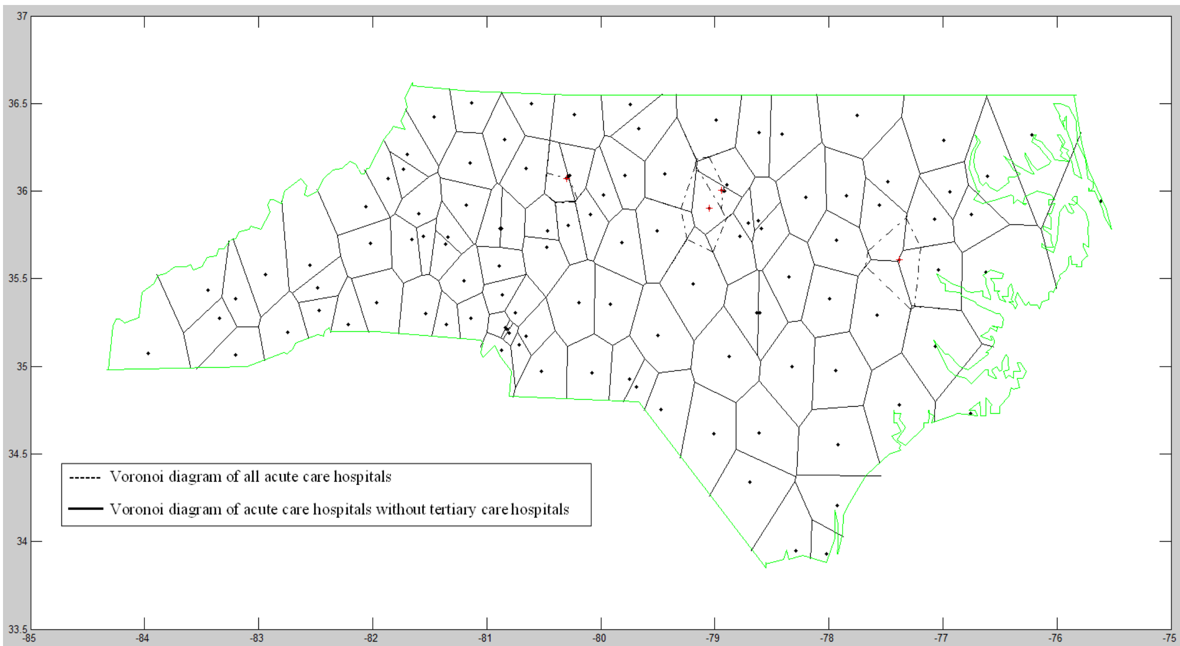

Figure 4.16: Voronoi Diagram for All Acute Care Hospitals vs. Voronoi Diagram for Acute Care Hospitals without Tertiary Care Hospitals

Figure 4.17 and Figure 4.18 show the difference between the calculated number of acute care beds and the number of acute care beds without the tertiary care hospitals. Figure 4.16 shows the deficit in acute care beds for each hospital while Figure 4.18 shows the surplus in acute care beds for each hospital according to our methodology. When we exclude the tertiary care hospitals, the balance among the remaining hospitals improves since the number of beds in a region is proportional to the population in that region. Furthermore, the difference between the largest surplus and the largest deficit declines.

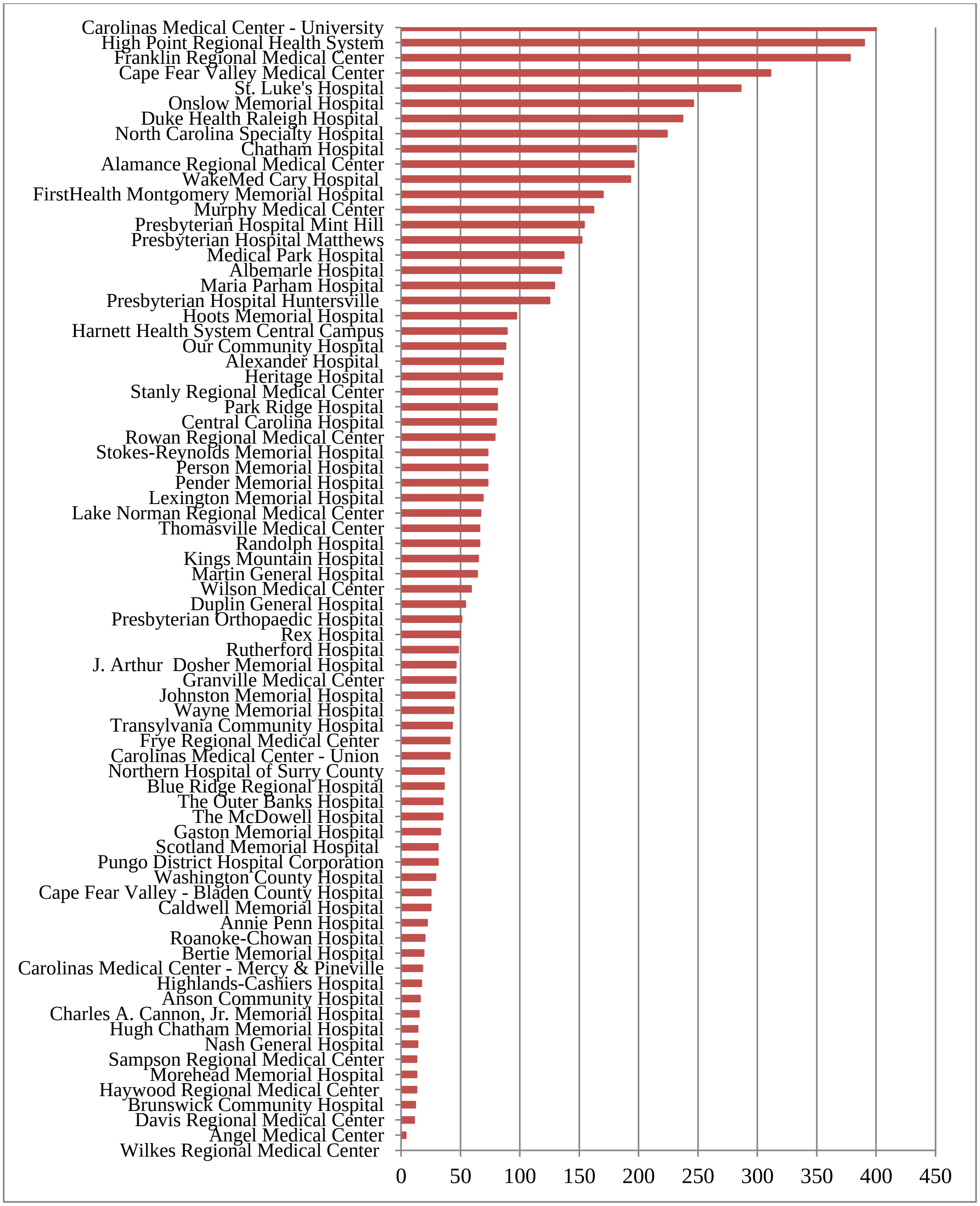

Figure 4.17: Deficit in Acute Care Bed for each Hospital according to Voronoi Approach*(University of North Carolina, Pitt County Memorial Hospital, Duke University Hospital, North Carolina Baptist Hospitals excluded)*

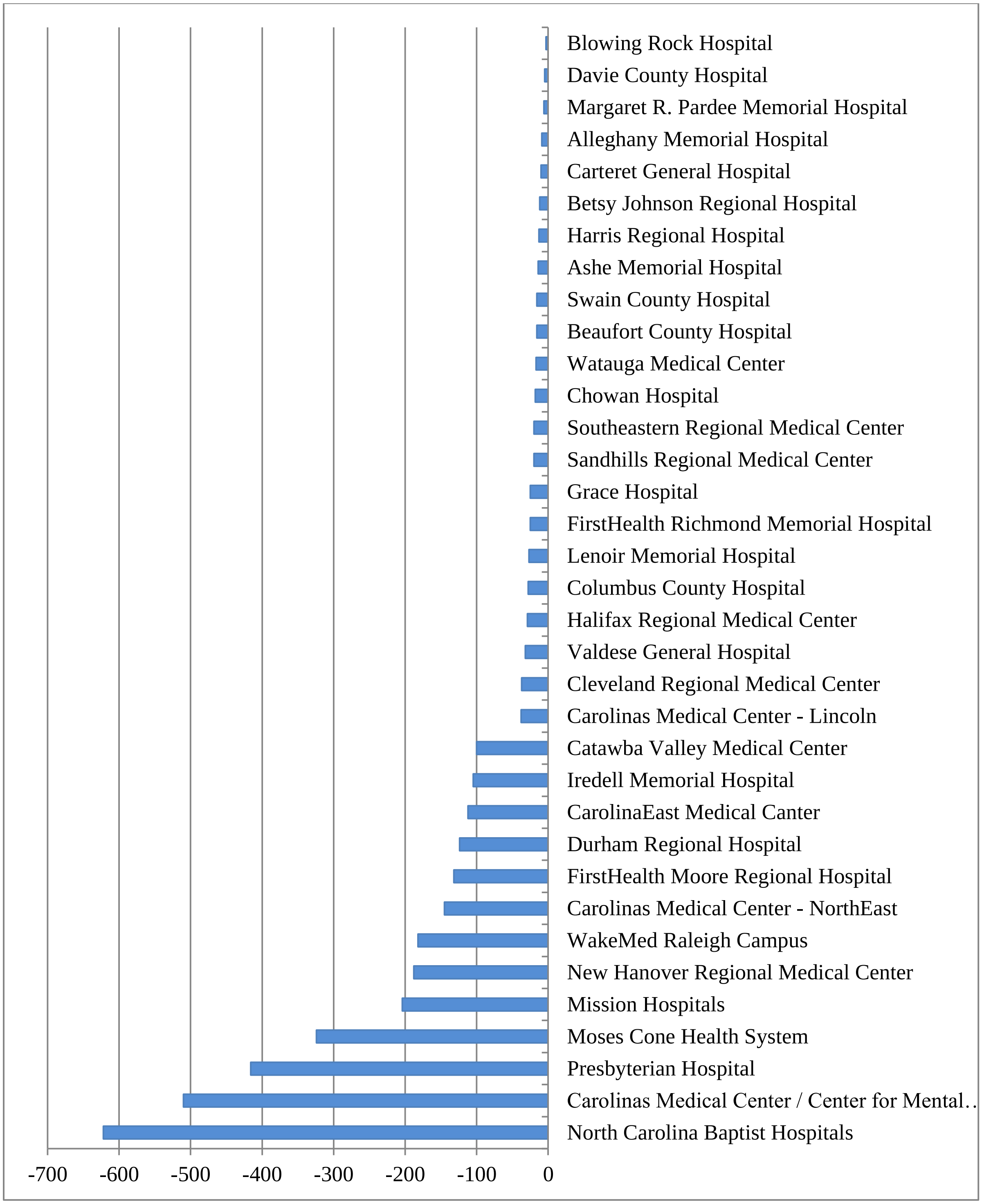

Figure 4.18: Surplus in Acute Care Bed for each Hospital according to Voronoi Approach (University of North Carolina, Pitt County Memorial Hospital, Duke University Hospital, North Carolina Baptist Hospitals excluded)

All the results, maps and charts show that the largest difference in acute care bed allocations between the current (SMFP) and proposed methodologies is for the hospitals that have the highest number of acute care days or for the hospitals whose service area has a large population but whose number of acute care beds calculated by the current (SMFP) methodology is not sufficient for the population.

Using Voronoi diagrams ensures geographic equity under the assumption of the equity of care provided by each bed. The population in this region determines the number of acute care beds and thus determines acute care hospital capacity. This capacity is not confined to county boundaries, but includes all the population in the service area.

4.2. Using Voronoi Diagram to Compare Proposals for Additional Acute Care Beds

In May 2011, three applicants submitted six competing proposals to the Certification of Need Section of the North Carolina Division of Health Service Regulation to develop additional acute care beds for Wake County. Since the North Carolina Division of Health Service Regulation announced the need as 101 additional acute care beds through the 2011 State Medical Facilities Plan, the three applicants, Wake Med, Rex Hospital and Novant Health, proposed additional beds as the following manner:

Wake Med proposes

- 79 additional acute care beds at its Raleigh campus on New Bern Avenue
- 22 additional acute care beds at WakeMed Cary Hospital on Kildaire Farm Road in Cary

Rex Hospital proposes

- 11 additional acute care beds and construction of a new bed tower to accommodate 115 existing acute care beds at its Raleigh campus on Lake Boone Trail
- A new 50-bed acute care hospital in Holly Springs
- A new 40-bed acute care hospital in the Wakefield area of northern Wake County

Novant Health proposes

- A new 50-bed acute care hospital in Holly Springs

These applications require either developing additional acute care beds for an existing acute care hospital or constructing a new acute care hospital and developing additional acute care beds for the new facility. The addresses of the new hospitals proposed by applicants are found and converted into longitude and latitude format. After that step, the Voronoi methodology above was applied for the proposals of Wake Med, Rex Hospital and Novant Health. Three Voronoi diagrams according to each applicant's proposals are created.

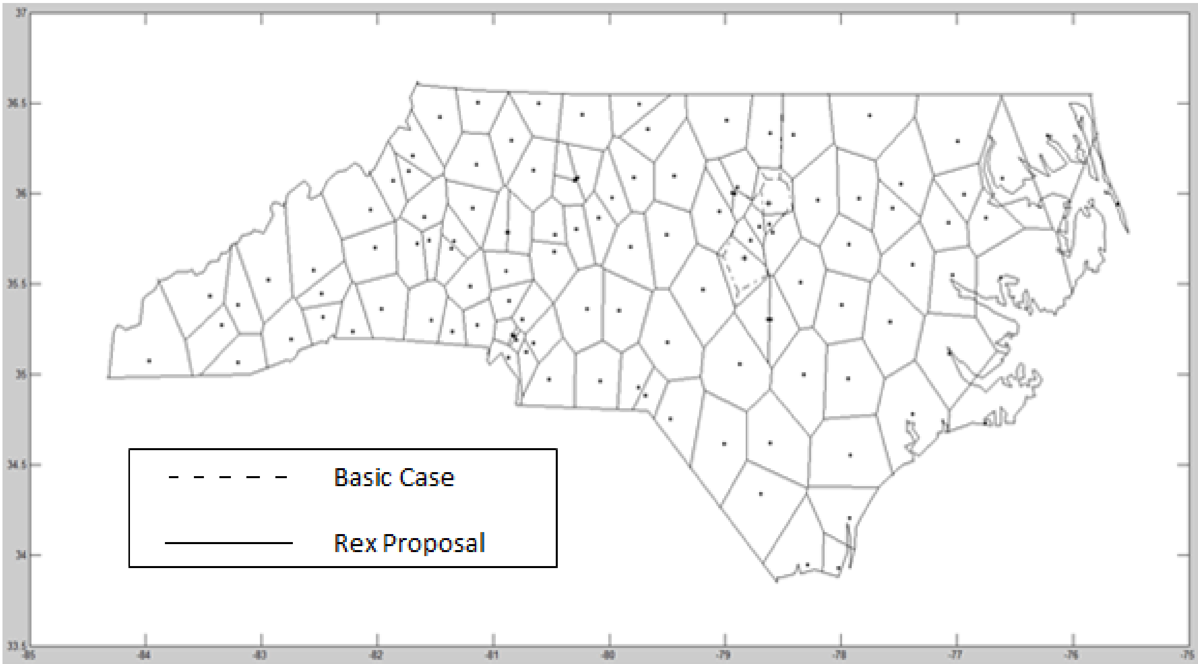

Figure 4.18: Voronoi Diagrams for Basic Case vs. Rex Proposal

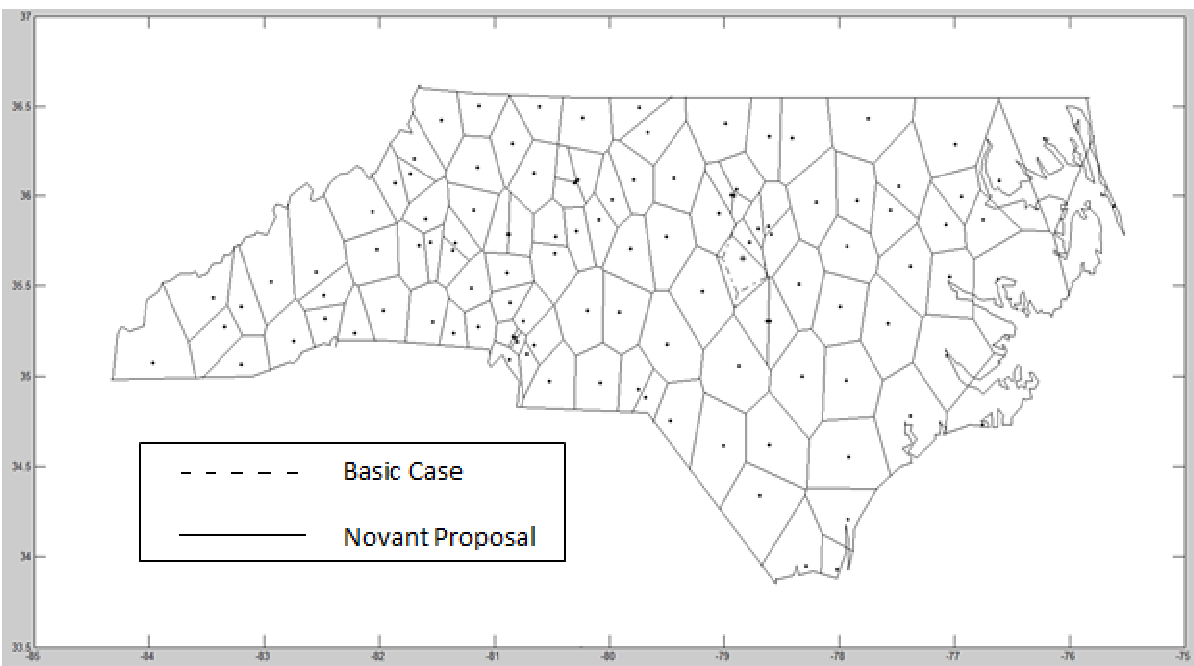

Figure 4.19: Voronoi Diagrams for Basic Case vs. Novant Proposal

The Voronoi diagrams presented in the Figure 4.18 are the Voronoi diagrams for the acute care hospitals including the new Hospitals, Rex Hospital in Holly Springs and Rex Hospital in Wakefield, proposed by Rex Hospital plotted on the Voronoi diagram for the basic case (excluding the new proposed hospitals), and Figure 4.19 shows the Voronoi diagrams for the acute care hospitals including the new Hospital, Novant Health in Holly Springs, proposed by Novant Health plotted on the Voronoi diagram for the basic case. The only differences between the Voronoi diagrams for the new case and basic case arise around the locations of the proposed new hospitals for both cases. The Voronoi diagram for Wake Med proposal looks exactly like the diagram for the base case since no new hospital is proposed by that applicant.

The same steps for population calculation in the first case are applied to these three Voronoi diagrams drawn for the acute care bed proposals. The results for the affected areas presented in Table 4.4. To compare these proposals, three main criteria are considered; variance and standard deviation in population, variance and standard deviation in number of acute care beds and maximum distance in each Voronoi polygon; in other words, we consider how geographically equal the population in each health service area is distributed.

Table 4.3: Comparison of Basic Case and Proposals according to Total squared deviation of per capita acute care beds in a service area from the statewide average and Maximum distance in Voronoi Polygons

	Basic Case	WakeMed Proposal	Rex Hospital Proposal	Novant Health Proposal
Percentage change in total squared deviation of per capita acute care beds in a service area from the statewide average	100.00%	100.02%	98.38%	99.19%
Average maximum distance(mile) in Health Service Area (Voronoi Polygon)	0.3072	0.3072	0.3037	0.3062

As presented in Table 4.3, Rex Hospital's proposal appears to be the best option in terms of the measure of equity that we use for our methodology. It has the lowest total squared deviation of per capita acute care beds in a service area from the statewide average, which is 98.38% of the Basic case. The Rex proposal also has the lowest average maximum distance, which means when we plot the hospitals presented in Rex proposal with the existing acute care hospitals, the average of the distances from each hospital to the farthest point on the Voronoi polygon for that hospital are less than those for WakeMed and Novant proposal. We also examined the maximum distance in each Voronoi polygon, i.e., the maximum distance from each hospital to the farthest point in its health service area. The distances are presented in Appendix E. The Novant Health proposal follows the Rex Hospital proposal with the second lowest values of each criterion. Wake Med Proposal has the poorest values for each criterion that we analyzed based on the methodology.

The changes in the shape of the Voronoi polygons after adding a new hospital also need to be examined. Figures 4.20 and 4.21 and results show that adding a new hospital creates a new Voronoi polygon (health service area) which affects only the area around that new hospital; the rest of the state is not affected.

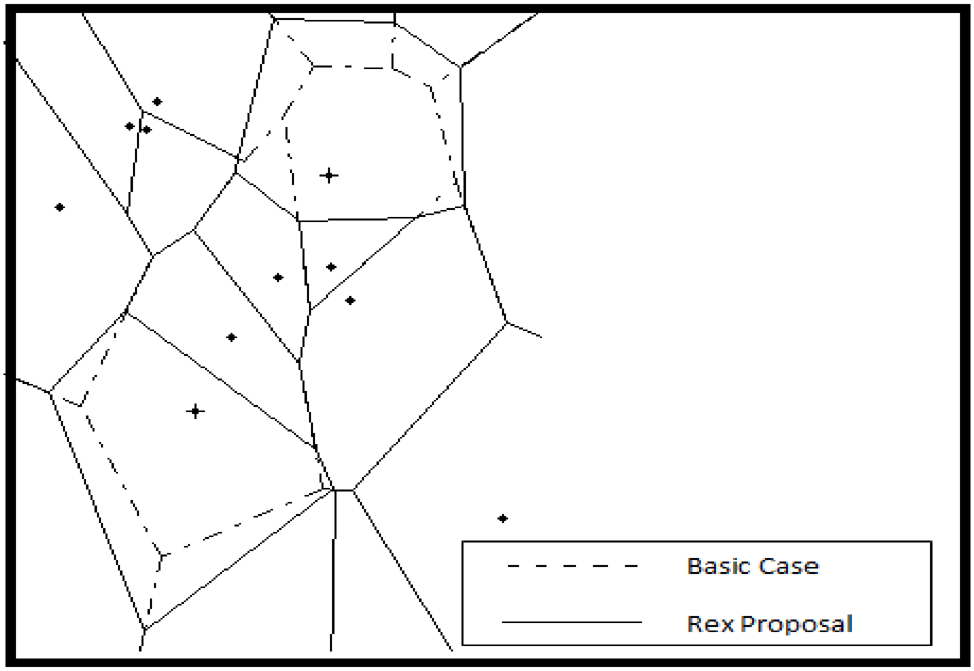

Figure 4.20: Effected Areas in Voronoi Diagrams for Basic Case vs. Rex Proposal

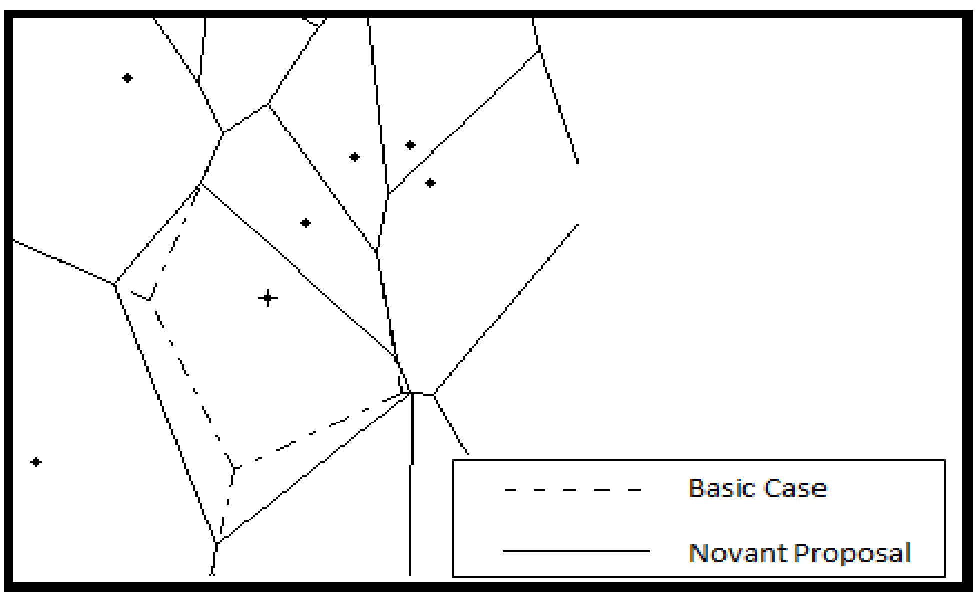

Figure 4.21: Effected Areas in Voronoi Diagrams for Basic Case vs. Novant Proposal

Table 4.4: Effects of Proposals in Wake County and Neighbor Counties

Hospital	County	Proposals							
		Basic		WakeMed		RexHospital		Novant Health	
		Bed Need	Max Distance	Bed Need	Max Distance	Bed Need	Max Distance	Bed Need	Max Distance
Granville Medical Center	Granville	45	0.2698	45	0.2698	35	0.2698	45	0.2698
Harnett Health System Central Campus	Harnett	89	0.2993	89	0.2993	70	0.2929	73	0.2568
Betsy Johnson Regional Hospital	Harnett	-13	0.2767	-13	0.2767	-13	0.2767	-13	0.2929
WakeMed Cary Hospital	Wake	198	0.2053	176	0.2053	161	0.1494	198	0.2053
Duke Health Raleigh Hospital	Wake	235	0.2755	235	0.2755	64	0.1458	235	0.2755
Rex Hospital	Wake	59	0.2993	59	0.2993	-111	0.1969	-114	0.2077
Rex HollySprings	Wake					160	0.2900		
Rex Wakefield	Wake					200	0.2452		
WakeMed Raleigh Campus	Wake	-224	0.2479	-303	0.2479	-228	0.2479	-224	0.2479
Novant HollySprings	Wake							160	0.2896

Table 4.4 presents the change in acute care beds in acute care hospitals in Wake County and beds in acute care hospitals of its neighbor counties which are affected by the change of redrawn Voronoi diagrams for the proposals and change in population. The first column in each case represents the acute care bed need, which is calculated by subtracting the number of acute care beds calculated through Voronoi diagram approach from the current number of acute care beds, and the second column in each case represents the maximum distance in each Voronoi polygon to present the maximum distance to the hospital in that Voronoi polygon (health service area).

Table 4.5: Comparison of affected Areas by Proposals according to Total squared deviation of per capita acute care beds in a service area from the statewide average and Average maximum distance in Voronoi Polygons

	Basic Case	WakeMed Proposal	Rex Hospital Proposal	Novant Health Proposal
Percentage change in total squared deviation of per capita acute care beds in a service area from the statewide average	100.00%	112.17%	126.79%	123.31%
Average maximum distance(mile) in Health Service Area (Voronoi Polygon)	0.2677	0.2677	0.2350	0.2557

Table 4.5 compares the Base case (only currently existing acute care hospitals), Wake Med proposal, Rex Hospital proposal, and Novant Health proposal just for the affected areas. Those affected areas are the Granville Medical Center, Harnett Health System Central Campus, Betsy Johnson Regional Hospital, WakeMed Cary, Duke Health Raleigh Hospital, Rex Hospital, Rex Holly Springs (proposed by Rex Hospital), Rex Wakefield (proposed by Rex Hospital), Wake Med Raleigh Campus, Novant Holly Springs (proposed by Novant Health), which are either geographically close to the additional hospitals proposed either by Rex Hospital or Novant Health or the regions created by those proposed hospitals. According to the total squared deviation of per capita acute care beds in a service area from the statewide average, which is the measure of equity that we assigned before, the Base case proposal has the best results; it has the minimum total squared deviation of per capita acute care beds in a service area from the statewide average. For the WakeMed Proposal, that measure of equity is 12.17% more than that for the Basic Case while this number becomes 23.31% worse than the Basic Case for the Novant Health Proposal. The total squared deviation of per capita acute care beds in a service area from the statewide average reaches the maximum for the Rex Hospital Proposal with an amount of 26.79% more than the Basic

Case. Addition to the total squared deviation of per capita acute care beds in a service area from the statewide average; we look the average of maximum distance (in mile) in each health service area (Voronoi polygon). This number is best in Rex Hospital proposal followed by Novant Health proposal and finally maximum for the Base case and the WakeMed proposal.

CHAPTER 5

Conclusions and Recommendations for Future Work

This research employs Voronoi diagrams to create hospital service areas that provide geographic equity and then computes the acute care bed needs from the population density according to those service areas. The politics of bed allocation is not addressed by this research and remains a significant factor in bed allocation policy decisions.

The first application in this study focuses on the size of the existing facilities and does not include the allocation of beds to new facilities, or recommend any new facilities while the second application compares proposed acute care beds and acute care hospitals. With the second application, we demonstrate that the Voronoi diagrams and related calculations can be used to compare different proposed projects. According to the objectives assigned previously, which are minimizing the total squared deviation of per capita acute care beds in a service area from the statewide average and minimizing the maximum distance in each Voronoi polygon (health service area of each hospital), we compare either the proposed Voronoi diagram approach with the current SMFP methodology or use the proposed approach to compare different proposed projects.

The planning of acute care beds is done by the State Medical Facilities Plan (SMFP), initially using a statewide average growth rate and using a county-specific growth rate without aggregating counties with small hospitals in the 2011 SMFC. This improvement does not seem sufficient because there are counties with one hospital, some with multiple hospitals, and even some without any hospital. This research is fundamentally different from the current approach since the allocation of beds is not limited by county boundaries, but instead defines a region of geographic equity using Voronoi diagrams by matching acute care beds to demand.

Instead of using a statewide growth rate or county-specific growth rate, we use a hospital based rate, which is presented as the Voronoi population. Also, by using census tracts for the calculation of Voronoi population, rather than counties as the population base, the population density is measured to a finer resolution. Even the counties without any acute care hospital and the population in that county are assigned to a health service area.

One key conclusion is that by creating regions of geographic equity and associating the population with the closest hospital, the geographic regions are established. The capacity to serve the area is determined by allocating sufficient capacity to each hospital.

To allocate capacity based on the geographical equity, we computed the acute care days and acute care bed needs from the population density in service area of each hospital. According to these calculations, there are hospitals where the difference between the numbers of acute care beds calculated using the Voronoi diagrams and the current number of acute care beds calculated by SMFP is positive, negative, or zero (stays the same). The main cause of deficits in acute care beds according to our research is the population. The population assigned to these service areas is very high, causing an increase in acute care days, and therefore number of acute care beds, while the acute care days and beds used in the SMFP are relatively small. The negative difference, a surplus in acute care beds according to our research, arises mainly in tertiary care hospitals, which are Duke University Hospital, North Carolina Baptist Hospitals, Forsyth Medical Center, Pitt County Memorial Hospital, University of North Carolina Hospitals, and Presbyterian hospital, whose acute care days and acute care beds accordingly are very high relative to those obtained by our research. The number of acute care days for these hospitals are high since the length of stay in these hospitals is more complex than that for a regular acute care hospital. This is as addressed in the revised Voronoi methodology, in which we exclude these tertiary care hospitals. After excluding them, we obtained a more balanced distribution of beds across hospitals, especially in terms of surpluses.

Since we assume that all acute care beds provide an equal level of care, the patients tend to go to the nearest hospital, which is assigned by the Voronoi diagram. In reality patients can prefer to some large hospitals such as an academic medical center teaching hospital, even though there is a closer hospital available. This tendency may also cause some of the unbalanced number of acute care days and acute care beds for hospitals. To check the assumption that patients go to the nearest hospital, we examined patient's behavior from the Hospital License Renewal data, which includes the number of acute care bed days at an acute care hospital provided to patients from other counties and neighbor states. For each hospital, we checked the proportion of the acute care days created by the patients reside in the same county as the hospital, the results are presented in the Appendix F. The average of that proportion for all acute care hospitals in North Carolina is 71%. This number is less than 40% for each tertiary care hospital.

There are some difficulties with the Voronoi approach that need to be addressed regarding the coastal areas, due to the limitations of using the straight line distance in that area. These problem are ignored at this stage since the area is very small relative to the total area of the state, and from the population point of view, only eight census tract center points fall that area.

Finally, the difference between computed acute care hospital beds and existing acute care hospital beds shows how geographic equity can be improved through the allocation of new beds or the reallocation of existing beds without considering the politics of bed allocation.

Improving some assumptions and the calculation of the population could be a part of future research. Since this study shows that Voronoi diagrams can be applied effectively to health facilities based on one of the most important considerations in healthcare delivery, which is population, this method could be applied to other types of health facilities.

This study also shows that Voronoi diagrams can be applied to one of the most important considerations in healthcare delivery, which is population-based service area. This method could be applied to other types of health facilities where geographic equity is an important consideration in facilities planning. In this context, this study could be extended by applying it to any other Certificate of Need (CON) target facilities. We could assess the geographic equity such as for operating rooms, nursing care facilities or even for the use of the technology and equipment under the CON regulation. Another extension for this study can be adding the growth rate for acute care days, which can give us the forecasted capacity for each acute care hospital in the State of North Carolina using both the growth rate in acute care days and projected population.

Another future extension of this study is using Voronoi diagrams in a genetic algorithm to find the optimum locations of another type of facility. The objective of this model is both minimizing the maximum distance in each service area and minimizing the variance in population in each service area.

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APPENDICES

APPENDIX A - *Acute Care Bed Need Projections*

	Projections based on Growth Factor at .01% per year for the next 6 years. Target Occupancy Factors: ADC<100 = 150%, ADC 100-200 = 140%, ADC>200 = 133%.									
A	B	C	D	E	F	G	H	I	J	K
License #	Facility Name	County	Licensed AC Beds	Adjustments for CONs and Previous Need	Thomson 2007 Acute Care Days	6 Years Growth at 0.01% Annually	20123 Projected Average Daily Census (ADC)	2013 Beds Adjusted for Target Occupancy	Projected 2013 Deficit (Bolded) or Surplus ("-")	2013 Need Determination
H0272	Alamance Regional Medical Center	Alamance	182	0	43,733	43,759	120	168	-14	
		Alamance Total	182	0						0
H0274	Alexander Hospital	Alexander	25	0	0	0	0	0	-25	
		Alexander Total	25	0						0
H0108	Alleghany Memorial Hospital	Alleghany	41	0	2,399	2,400	7	10	-31	
		Alleghany Total	41	0						0
H0082	Anson Community Hospital	Anson	52	0	5,367	5,370	15	22	-30	
		Anson Total	52	0						0
H0099	Ashe Memorial Hospital	Ashe	76	0	5,070	5,073	14	21	-55	
		Ashe Total	76	0						0
H0037	Charles A. Cannon, Jr. Memorial Hospital	Avery	30	0	5,965	5,969	16	25	-5	
		Avery Total	30	0						0
H0188	Beaufort County Hospital	Beaufort	120	0	10,684	10,690	29	44	-76	
H0002	Pungo District Hospital Corporation	Beaufort	39	0	2,369	2,370	6	10	-29	0
		Beaufort Total	159	0						
H0268	Bertie Memorial Hospital	Bertie	6	0	1,566	1,567	4	6	**0**	
		Bertie Total	6	0						0
H0154	Cape Fear Valley - Bladen County Hospital	Bladen	48	0	4,729	4,732	13	19	-29	
		Bladen Total	48	0						0
H0250	Brunswick Community Hospital	Brunswick	60	0	11,205	11,212	31	46	-14	
H0150	J. Arthur Dosher Memorial Hospital	Brunswick	36	0	4,696	4,699	13	19	-17	0
		Brunswick Total	96	0						
H0036	Mission Hospitals	Buncombe	673	0	182,390	182,499	500	665	-8	
		Buncombe Total	673	0						0
H0062	Grace Hospital	Burke	162	0	20,151	20,163	55	83	-79	
H0091	Valdese General Hospital	Burke	131	0	12,151	12,158	33	50	-81	0
		Burke Total	293	0						
H0031	Carolinas Medical Center - NorthEast	Cabarrus	447	0	98,475	98,534	270	359	-88	
		Cabarrus Total	447	0						0
H0061	Caldwell Memorial Hospital	Caldwell	110	0	15,095	15,104	41	62	-48	
		Caldwell Total	110	0						0
H0222	Carteret General Hospital	Carteret	135	0	28,952	28,969	79	119	-16	
		Carteret Total	135	0						0
H0223	Catawba Valley Medical Center	Catawba	200	0	39,233	39,257	108	151	-49	
H0053	Frye Regional Medical Center	Catawba	209	0	48,577	48,606	133	186	-23	0
		Catawba Total	409	0						
H0007	Chatham Hospital	Chatham	25	0	2,855	2,857	8	12	-13	
		Chatham Total	25	0						0
H0239	Murphy Medical Center	Cherokee	57	0	8,000	8,005	22	33	-24	
		Cherokee Total	57	0						0

Projections based on Growth Factor at .01% per year for the next 6 years. Target Occupancy Factors: ADC<100 = 150%, ADC 100-200 = 140%, ADC>200 = 133%.

A	B	C	D	E	F	G	H	I	J	K
License #	Facility Name	County	Licensed AC Beds	Adjustments for CONs and Previous Need	Thomson 2007 Acute Care Days	6 Years Growth at 0.01% Annually	2013 Projected Average Daily Census (ADC)	2013 Beds Adjusted for Target Occupancy	Projected 2013 Deficit (Bolded) or Surplus ("-")	2013 Need Determination
H0261	Franklin Regional Medical Center	Franklin	70	0	13,645	13,653	37	56	-14	0
		Franklin Total	70	0						
H0105	Gaston Memorial Hospital	Gaston	372	0	87,990	88,043	241	321	-51	0
		Gaston Total	372	0						
H0098	Granville Medical Center	Granville	62	0	7,280	7,284	20	30	-32	0
		Granville Total	62	0						
H0052	High Point Regional Health System	Guilford	291	16	72,495	72,539	199	278	-29	0
H0159	Moses Cone Health System	Guilford	818	-41	192,620	192,736	528	702	-75	
		Guilford Total	1,109	-25						
H0230	Halifax Regional Medical Center	Halifax	186	0	33,124	33,144	91	136	-50	0
H0004	Our Community Hospital	Halifax	20	0	139	139	0	1	-19	
		Halifax Total	206	0						
H0224	Betsy Johnson Regional Hospital	Harnett	101	0	28,675	28,692	79	118	17	0
N/A	Harnett Health System Central Campus	Harnett	0	50	0	0	0	0	-50	
Totals	*Betsy Johnson/Harnett Health System Totals*		101	50					-33	
H0080	Good Hope Hospital (closed effective 4/11/06)	Harnett	0	34	0	0	0	0	-34	
		Harnett Total	101	84						
H0025	Haywood Regional Medical Center	Haywood	153	0	21,412	21,425	59	88	-65	0
		Haywood Total	153	0						
H0161	Margaret R. Pardee Memorial Hospital	Henderson	193	0	26,797	26,813	73	110	-83	0
H0019	Park Ridge Hospital	Henderson	62	0	13,397	13,405	37	55	-7	
		Henderson Total	255	0						
H0001	Roanoke-Chowan Hospital	Hertford	86	0	15,220	15,229	42	63	-23	0
		Hertford Total	86	0						
H0248	Davis Regional Medical Center	Iredell	120	-18	16,644	16,654	46	68	-34	0
H0259	Lake Norman Regional Medical Center	Iredell	105	18	27,757	27,774	76	114	-9	
Totals	*Davis Regional/Lake Norman Totals*		225	0					-42	
H0164	Iredell Memorial Hospital	Iredell	199	0	41,817	41,842	115	160	-39	
		Iredell Total	424	0						
H0087	Harris Regional Hospital	Jackson	86	0	19,445	19,457	53	80	-6	0
		Jackson Total	86	0						
H0151	Johnston Memorial Hospital	Johnston	157	22	38,576	38,599	106	148	-31	0
		Johnston Total	157	22						
H0243	Central Carolina Hospital	Lee	127	0	20,645	20,657	57	85	-42	0
		Lee Total	127	0						
H0043	Lenoir Memorial Hospital	Lenoir	218	0	43,336	43,362	119	166	-52	0
		Lenoir Total	218	0						
H0225	Carolinas Medical Center - Lincoln	Lincoln	101	0	15,624	15,633	43	64	-37	0
		Lincoln Total	101	0						

	Projections based on Growth Factor at .01% per year for the next 6 years. Target Occupancy Factors: ADC<100 = 150%, ADC 100-200 = 140%, ADC>200 = 133%.									
A	***B***	***C***	***D***	***E***	***F***	***G***	***H***	***I***	***J***	***K***
License #	***Facility Name***	***County***	***Licensed AC Beds***	***Adjustments for CONs and Previous Need***	***Thomson 2007 Acute Care Days***	***6 Years Growth at 0.01% Annually***	***2013 Projected Average Daily Census (ADC)***	***2013 Beds Adjusted for Target Occupancy***	***Projected 2013 Deficit (Bolded) or Surplus ("-")***	***2013 Need Determination***
H0034	Angel Medical Center	Macon	59	0	5,655	5,658	16	23	-36	0
H0193	Highlands-Cashiers Hospital	Macon	24	0	756	756	2	3	-21	
		Macon Total	83	0						
H0078	Martin General Hospital	Martin	49	0	7,894	7,899	22	32	-17	0
		Martin Total	49	0						
H0097	The McDowell Hospital	McDowell	65	0	7,307	7,311	20	30	-35	0
		McDowell Total	65	0						
H0042	Carolinas Medical Center - Mercy & Pineville	Mecklenburg	294	36	56,294	56,328	154	216	-114	30
H0255	Carolinas Medical Center - University	Mecklenburg	130	-36	21,378	21,391	59	88	-6	
H0071	Carolinas Medical Center / Center for Mental Health	Mecklenburg	795	0	228,343	228,480	626	833	38	
Totals	*Carolinas Medical Center Totals*		1,219	0					-82	
H0010	Presbyterian Hospital	Mecklenburg	463	76	159,139	159,235	436	580	41	
H0282	Presbyterian Hospital Huntersville	Mecklenburg	50	0	15,993	16,003	44	66	16	
H0270	Presbyterian Hospital Matthews	Mecklenburg	102	0	27,408	27,424	75	113	11	
N/A	Presbyterian Hospital Mint Hill	Mecklenburg	0	50	Utilization for reporting period shown with Presb Ortho.				-50	
H0251	Presbyterian Orthopaedic Hospital	Mecklenburg	140	-126	12,915	12,923	35	53	39	
Totals	*Presbyterian Hospital Totals*		755	0					57	
	2008 SMFP Need Determination	Mecklenburg		27						
		Mecklenburg Total	1,974	27						
H0169	Blue Ridge Regional Hospital	Mitchell	46	0	6,410	6,414	18	26	-20	0
		Mitchell Total	46	0						
H0003	FirstHealth Montgomery Memorial Hospital	Montgomery	37	0	1,568	1,569	4	6	-31	0
		Montgomery Total	37	0						
H0100	FirstHealth Moore Regional Hospital	Moore	297	23	78,816	78,863	216	287	-33	0
		Moore Total	297	23						
H0228	Nash General Hospital	Nash	270	0	58,151	58,186	159	223	-47	0
		Nash Total	270	0						
H0221	New Hanover Regional Medical Center	New Hanover	647	0	147,013	147,101	403	536	-111	0
		New Hanover Total	647	0						
H0048	Onslow Memorial Hospital	Onslow	162	0	32,776	32,796	90	135	-27	0
		Onslow Total	162	0						
H0157	University of North Carolina Hospitals	Orange	621	72	193,172	193,288	530	704	11	0
		Orange Total	621	72						
H0054	Albemarle Hospital	Pasquotank	182	0	31,121	31,140	85	128	-54	0
		Pasquotank Total	182	0						
H0115	Pender Memorial Hospital	Pender	43	0	3,603	3,605	10	15	-28	0
		Pender Total	43	0						
H0066	Person Memorial Hospital	Person	50	0	11,868	11,875	33	49	-1	0
		Person Total	50	0						
H0104	Pitt County Memorial Hospital	Pitt	628	106	196,651	196,769	539	717	-17	0
		Pitt Total	628	106						

	Projections based on Growth Factor at .01% per year for the next 6 years. Target Occupancy Factors: ADC<100 = 150%, ADC 100-200 = 140%, ADC>200 = 133%.									
A	B	C	D	E	F	G	H	I	J	K
License #	Facility Name	County	Licensed AC Beds	Adjustments for CONs and Previous Need	Thomson 2007 Acute Care Days	6 Years Growth at 0.01% Annually	2013 Projected Average Daily Census (ADC)	2013 Beds Adjusted for Target Occupancy	Projected 2013 Deficit (Bolded) or Surplus ("-")	2013 Need Determination
H0079	St. Luke's Hospital	Polk	45	0	3,493	3,495	10	14	-31	0
		Polk Total	45	0						
H0013	Randolph Hospital	Randolph	145	0	24,464	24,479	67	101	-44	0
		Randolph Total	145	0						
H0158	FirstHealth Richmond Memorial Hospital	Richmond	99	0	14,171	14,180	39	58	-41	0
H0265	Sandhills Regional Medical Center	Richmond	54	6	13,227	13,235	36	54	-6	
		Richmond Total	153	6						
H0064	Southeastern Regional Medical Center	Robeson	292	0	61,776	61,813	169	237	-55	0
		Robeson Total	292	0						
H0023	Annie Penn Hospital	Rockingham	110	0	16,465	16,475	45	68	-42	0
H0072	Morehead Memorial Hospital	Rockingham	108	0	24,150	24,164	66	99	-9	
		Rockingham Total	218	0						
H0040	Rowan Regional Medical Center	Rowan	223	0	35,958	35,980	99	148	-75	0
		Rowan Total	223	0						
H0039	Rutherford Hospital	Rutherford	129	0	18,989	19,000	52	78	-51	0
		Rutherford Total	129	0						
H0067	Sampson Regional Medical Center	Sampson	116	0	15,749	15,758	43	65	-51	0
		Sampson Total	116	0						
H0107	Scotland Memorial Hospital	Scotland	97	21	24,557	24,572	67	101	-17	0
		Scotland Total	97	21						
H0008	Stanly Regional Medical Center	Stanly	97	0	14,763	14,772	40	61	-36	0
		Stanly Total	97	0						
H0165	Stokes-Reynolds Memorial Hospital	Stokes	53	0	1,365	1,366	4	6	-47	0
		Stokes Total	53	0						
H0049	Hugh Chatham Memorial Hospital	Surry	81	0	16,475	16,485	45	68	-13	0
H0184	Northern Hospital of Surry County	Surry	100	0	16,678	16,688	46	69	-31	
		Surry Total	181	0						
H0069	Swain County Hospital	Swain	48	0	1,645	1,646	5	7	-41	0
		Swain Total	48	0						
H0111	Transylvania Community Hospital	Transylvania	42	0	6,406	6,410	18	26	-16	0
		Transylvania Total	42	0						
H0050	Carolinas Medical Center - Union	Union	157	0	36,629	36,651	100	141	-16	0
		Union Total	157	0						
H0267	Maria Parham Hospital	Vance	91	0	20,106	20,118	55	83	-8	0
		Vance Total	91	0						

	Projections based on Growth Factor at .01% per year for the next 6 years. Target Occupancy Factors: ADC<100 = 150%, ADC 100-200 = 140%, ADC>200 = 133%.									
A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*
License #	*Facility Name*	*County*	*Licensed AC Beds*	*Adjustments for CONs and Previous Need*	*Thomson 2007 Acute Care Days*	*6 Years Growth at 0.01% Annually*	*2013 Projected Average Daily Census (ADC)*	*2013 Beds Adjusted for Target Occupancy*	*Projected 2013 Deficit (Bolded) or Surplus ("-")*	*2013 Need Determination*
H0238	Duke Health Raleigh Hospital	Wake	186	0	23,185	23,199	64	95	-91	18
H0065	Rex Hospital	Wake	388	45	101,520	101,581	278	370	-63	
H0276	WakeMed Cary Hospital	Wake	156	0	36,625	36,647	100	141	-15	
H0199	WakeMed Raleigh Campus	Wake	515	60	175,351	175,456	481	639	64	
Totals	*WakeMed Totals*		671	60					49	
	2008 SMFP Need Determination	Wake		41						
		Wake Total	1,245	146						
Wake County 2013 Need Determination for 18 beds results from an Adjusted Need Determination petition. The 18 beds are to be designated as licensed neonatal beds only.										
H0006	Washington County Hospital	Washington	49	-37	2,140	2,141	6	9	-3	0
		Washington Total	49	-37						
H0160	Blowing Rock Hospital	Watauga	28	0	683	683	2	3	-25	0
H0077	Watauga Medical Center	Watauga	117	0	22,661	22,675	62	93	-24	
		Watauga Total	145	0						
H0257	Wayne Memorial Hospital	Wayne	255	0	59,380	59,416	163	228	-27	0
		Wayne Total	255	0						
H0153	Wilkes Regional Medical Center	Wilkes	120	0	17,707	17,718	49	73	-47	0
		Wilkes Total	120	0						
H0210	Wilson Medical Center	Wilson	294	-96	33,691	33,711	92	139	-59	0
		Wilson Total	294	-96						
H0155	Hoots Memorial Hospital	Yadkin	22	0	1,002	1,003	3	4	-18	0
		Yadkin Total	22	0						

APPENDIX B - *The Acute Care Bed Need Projections according to Proposed Methodology*

Hospital	County	Voronoi Population	Acute Care Days	Number of Licensed Bed (w/o Adjustments)	Adjustments	Number of Licensed Bed	Computed Acute Care Days	Computed Number of Beds	Computed Bed -Licensed Bed
Alamance Regional Medical Center	Alamance	145,870	45,843	182	0	182	81,759	378	196
Alexander Hospital	Alexander	42,840	0	25	0	25	24,011	111	86
Alleghany Memorial Hospital	Alleghany	12,260	2,785	41	0	41	6,872	32	-9
Anson Community Hospital	Anson	26,120	4,152	52	0	52	14,640	68	16
Ashe Memorial Hospital	Ashe	23,850	5,182	76	0	76	13,368	62	-14
Charles A. Cannon, Jr. Memorial Hospital	Avery	17,450	6,433	30	0	30	9,781	45	15
Pungo District Hospital Corporation	Beaufort	27,150	2,259	39	0	39	15,217	70	31
Beaufort County Hospital	Beaufort	40,260	7,987	120	0	120	22,565	104	-16
Bertie Memorial Hospital	Bertie	9,840	1,578	6	0	6	5,515	25	19
Cape Fear Valley - Bladen County Hospital	Bladen	28,170	3,794	48	0	48	15,789	73	25
J. Arthur Dosher Memorial Hospital	Brunswick	31,670	4,630	36	0	36	17,751	82	46
Brunswick Community Hospital	Brunswick	33,420	11,513	60	14	74	18,732	86	12
Mission Hospitals	Buncombe	181,120	186,888	673	0	673	101,516	469	-204
Grace Hospital	Burke	53,070	20,541	162	0	162	29,745	137	-25
Valdese General Hospital	Burke	38,330	11,794	131	0	131	21,484	99	-32
Carolinas Medical Center - NorthEast	Cabarrus	116,800	105,542	447	0	447	65,465	302	-145
Caldwell Memorial Hospital	Caldwell	52,280	17,505	110	0	110	29,302	135	25
Carteret General Hospital	Carteret	48,340	27,483	135	0	135	27,094	125	-10
Frye Regional Medical Center	Catawba	96,540	47,695	209	0	209	54,110	250	41
Catawba Valley Medical Center	Catawba	38,450	39,713	200	0	200	21,551	100	-100
Chatham Hospital	Chatham	86,020	3,341	25	0	25	48,213	223	198
Murphy Medical Center	Cherokee	32,230	8,473	57	0	57	18,065	83	26
Chowan Hospital	Chowan	12,010	6,988	49	0	49	6,731	31	-18
Kings Mountain Hospital	Cleveland	53,070	7,025	72	0	72	29,745	137	65
Cleveland Regional Medical Center	Cleveland	78,850	37,156	241	0	241	44,195	204	-37
Columbus County Hospital	Columbus	48,520	18,581	154	0	154	27,195	126	-28
CarolinaEast Medical Canter	Craven	75,400	77,706	270	37	307	42,261	195	-112
Cape Fear Valley Medical Center	Cumberland	325,150	145,017	487	44	531	182,243	842	311
The Outer Banks Hospital	Dare	32,660	3,634	21	0	21	18,306	85	64

Hospital	County	Voronoi Population	Acute Care Days	Number of Licensed Bed (w/o Adjustments)	Adjustments	Number of Licensed Bed	Computed Acute Care Days	Computed Number of Beds	Computed Bed -Licensed Bed
Lexington Memorial Hospital	Davidson	62,870	11,231	94	0	94	35,238	163	69
Thomasville Medical Center	Davidson	72,960	12,900	123	0	123	40,893	189	66
Davie County Hospital	Davie	29,330	1,420	81	0	81	16,439	76	-5
Duplin General Hospital	Duplin	44,320	11,401	61	0	61	24,841	115	54
North Carolina Specialty Hospital	Durham	93,370	3,248	18	0	18	52,333	242	224
Durham Regional Hospital	Durham	74,240	64,752	316	0	316	41,611	192	-124
Duke University Hospital	Durham	74,970	242,051	924	0	924	42,020	194	-730
Heritage Hospital	Edgecombe	32,590	15,631	101	0	101	18,266	84	-17
Medical Park Hospital	Forsyth	61,430	4,906	22	0	22	34,431	159	137
Forsyth Medical Center	Forsyth	76,590	210,295	751	52	803	42,928	198	-605
North Carolina Baptist Hospitals	Forsyth	173,070	218,898	789	13	802	97,004	448	-354
Franklin Regional Medical Center	Franklin	67,000	11,342	70	0	70	37,553	173	103
Gaston Memorial Hospital	Gaston	156,570	81,162	372	0	372	87,756	405	33
Granville Medical Center	Granville	41,640	8,077	62	0	62	23,339	108	46
High Point Regional Health System	Guilford	269,290	67,906	291	16	307	150,934	697	390
Moses Cone Health System	Guilford	175,080	192,429	759	18	777	98,130	453	-324
Our Community Hospital	Halifax	21,470	52	20	0	20	12,034	56	36
Halifax Regional Medical Center	Halifax	61,110	33,056	186	0	186	34,251	158	-28
Harnett Health System Central Campus	Harnett	53,760	0	0	50	50	30,132	139	89
Betsy Johnson Regional Hospital	Harnett	34,420	27,358	101	0	101	19,292	89	-12
Haywood Regional Medical Center	Haywood	64,020	14,217	153	0	153	35,882	166	13
Park Ridge Hospital	Henderson	54,360	14,135	62	0	62	30,468	141	79
Margaret R. Pardee Memorial Hospital	Henderson	62,940	23,211	193	0	193	35,277	163	-30
Roanoke-Chowan Hospital	Hertford	41,570	14,323	86	0	86	23,300	108	22
Lake Norman Regional Medical Center	Iredell	73,390	27,321	105	18	123	41,134	190	67
Davis Regional Medical Center	Iredell	43,480	16,476	120	-18	102	24,370	113	11
Iredell Memorial Hospital	Iredell	36,450	40,708	199	0	199	20,430	94	-105
Harris Regional Hospital	Jackson	28,370	18,293	86	0	86	15,901	73	-13
Johnston Memorial Hospital	Johnston	86,630	37,952	157	22	179	48,555	224	45
Central Carolina Hospital	Lee	79,950	19,687	127	0	127	44,811	207	80

Hospital	County	Voronoi Population	Acute Care Days	Number of Licensed Bed (w/o Adjustments)	Adjustments	Number of Licensed Bed	Computed Acute Care Days	Computed Number of Beds	Computed Bed -Licensed Bed
Lenoir Memorial Hospital	Lenoir	73,640	46,226	218	0	218	41,274	191	-27
Carolinas Medical Center - Lincoln	Lincoln	24,470	15,253	101	0	101	13,715	63	-38
Angel Medical Center	Macon	24,340	5,607	59	0	59	13,642	63	4
Highlands-Cashiers Hospital	Macon	15,800	919	24	0	24	8,856	41	17
Martin General Hospital	Martin	43,580	7,965	49	0	49	24,426	113	64
The McDowell Hospital	McDowell	38,780	6,525	65	0	65	21,736	100	35
Presbyterian Orthopaedic Hospital	Mecklenburg	25,210	12,803	140	-126	14	14,130	65	51
Carolinas Medical Center - University	Mecklenburg	190,840	21,979	130	-36	94	106,964	494	400
Presbyterian Hospital Matthews	Mecklenburg	102,820	30,779	102	12	114	57,629	266	152
Presbyterian Hospital Huntersville	Mecklenburg	77,150	17,081	60	15	75	43,242	200	125
Presbyterian Hospital Mint Hill	Mecklenburg	78,880	0	0	50	50	44,211	204	154
Presbyterian Hospital	Mecklenburg	47,450	154,618	463	76	539	26,595	123	-416
Carolinas Medical Center - Mercy & Pineville	Mecklenburg	134,470	61,844	294	36	330	75,369	348	18
Carolinas Medical Center / Center for Mental Health	Mecklenburg	110,140	233,864	795	0	795	61,732	285	-510
Blue Ridge Regional Hospital	Mitchell	31,680	6,568	46	0	46	17,756	82	36
FirstHealth Montgomery Memorial Hospital	Montgomery	76,260	1,835	37	0	37	42,743	197	160
FirstHealth Moore Regional Hospital	Moore	72,750	73,264	297	23	320	40,776	188	-132
Nash General Hospital	Nash	94,510	56,687	270	0	270	52,972	245	-25
New Hanover Regional Medical Center	New Hanover	177,440	139,307	647	0	647	99,453	459	-188
Onslow Memorial Hospital	Onslow	157,670	33,350	162	0	162	88,372	408	246
University of North Carolina Hospitals	Orange	122,620	199,848	621	72	693	68,727	317	-376
Albemarle Hospital	Pasquotank	33,120	27,437	182	0	182	18,563	86	-96
Pender Memorial Hospital	Pender	45,010	5,647	43	0	43	25,228	116	73
Person Memorial Hospital	Person	47,590	9,717	50	0	50	26,674	123	73
Pitt County Memorial Hospital	Pitt	124,580	197,218	667	67	734	69,826	322	-412
St. Luke's Hospital	Polk	18,840	3,521	45	0	45	10,560	49	4
Randolph Hospital	Randolph	81,620	27,782	145	0	145	45,747	211	66
Sandhills Regional Medical Center*	Richmond	15,440	11,962	54	6	60	8,654	40	-20
FirstHealth Richmond Memorial Hospital	Richmond	28,620	12,731	99	0	99	16,041	74	-25
Southeastern Regional Medical Center	Robeson	105,250	60,085	292	0	292	58,991	272	-20

Hospital	County	Voronoi Population	Acute Care Days	Number of Licensed Bed (w/o Adjustments)	Adjustments	Number of Licensed Bed	Computed Acute Care Days	Computed Number of Beds	Computed Bed -Licensed Bed
Annie Penn Hospital	Rockingham	50,890	13,555	110	0	110	28,523	132	22
Morehead Memorial Hospital	Rockingham	46,570	21,894	108	0	108	26,102	121	13
Rowan Regional Medical Center	Rowan	116,770	34,559	223	0	223	65,448	302	79
Rutherford Hospital	Rutherford	60,720	17,359	129	0	129	34,033	157	28
Sampson Regional Medical Center	Sampson	50,010	12,653	116	0	116	28,030	129	13
Scotland Memorial Hospital	Scotland	57,660	24,706	97	21	118	32,318	149	31
Stanly Regional Medical Center	Stanly	68,730	14,101	97	0	97	38,522	178	81
Stokes-Reynolds Memorial Hospital	Stokes	48,540	842	53	0	53	27,206	126	73
Northern Hospital of Surry County	Surry	52,600	15,719	100	0	100	29,482	136	36
Hugh Chatham Memorial Hospital	Surry	36,570	18,817	81	0	81	20,497	95	14
Swain County Hospital	Swain	12,430	1,607	48	0	48	6,967	32	-16
Transylvania Community Hospital	Transylvania	32,900	5,829	42	0	42	18,440	85	43
Carolinas Medical Center - Union	Union	76,570	40,362	157	0	157	42,917	198	41
Maria Parham Hospital	Vance	69,020	19,892	91	0	91	38,685	179	88
WakeMed Cary Hospital	Wake	134,780	38,542	156	0	156	75,543	349	193
Duke Health Raleigh Hospital	Wake	160,030	23,215	186	0	186	89,695	414	228
Rex Hospital	Wake	186,640	106,947	425	8	433	104,610	483	50
WakeMed Raleigh Campus	Wake	153,520	177,318	515	113	628	86,046	397	-231
Washington County Hospital	Washington	15,870	1,849	49	-37	12	8,895	41	29
Blowing Rock Hospital	Watauga	9,760	585	28	0	28	5,470	25	-3
Watauga Medical Center	Watauga	38,530	21,199	117	0	117	21,596	100	-17
Wayne Memorial Hospital	Wayne	115,510	60,022	255	0	255	64,742	299	44
Wilkes Regional Medical Center	Wilkes	46,450	16,184	120	0	120	26,035	120	0
Wilson Medical Center	Wilson	86,700	34,631	294	-96	198	48,594	224	26
Hoots Memorial Hospital	Yadkin	46,000	1,069	22	0	22	25,782	119	97
		8,049,320	4,511,554			20,833			
							AC Days per Population	**AC Beds per AC Days**	
							0.560488836	0.004617699	

APPENDIX C – *Comparison of Max Distances according to Voronoi and SMFP Methodology*

Hospital	County	Max Distance Voronoi	Max Distance County
Alamance Regional Medical Center	Alamance	0.3440	0.3226
Alexander Hospital	Alexander	0.2784	0.1986
Alleghany Memorial Hospital	Alleghany	0.1229	0.2359
Anson Community Hospital	Anson	0.2695	0.3110
Ashe Memorial Hospital	Ashe	0.2125	0.2810
Charles A. Cannon, Jr. Memorial Hospital	Avery	0.2258	0.2201
Pungo District Hospital Corporation	Beaufort	0.6206	0.7542
Beaufort County Hospital	Beaufort	0.3077	1.1697
Bertie Memorial Hospital	Bertie	0.2819	0.4149
Cape Fear Valley - Bladen County Hospital	Bladen	0.4041	0.4614
J. Arthur Dosher Memorial Hospital	Brunswick	0.1546	0.6288
Brunswick Community Hospital	Brunswick	0.2350	0.4718
Mission Hospitals	Buncombe	0.4986	0.5606
Grace Hospital	Burke	0.2593	0.3707
Valdese General Hospital	Burke	0.2246	0.4462
Carolinas Medical Center - NorthEast	Cabarrus	0.1631	0.6105
Caldwell Memorial Hospital	Caldwell	0.2898	0.3242
Carteret General Hospital	Carteret	0.3141	3.5436
Frye Regional Medical Center	Catawba	0.2293	0.4301
Catawba Valley Medical Center	Catawba	0.2246	0.4433
Chatham Hospital	Chatham	0.3157	2.9985
Murphy Medical Center	Cherokee	0.5203	0.5246
Chowan Hospital	Chowan	0.3198	0.7183
Kings Mountain Hospital	Cleveland	0.1979	0.4796
Cleveland Regional Medical Center	Cleveland	0.2599	0.3216

Hospital	County	Max Distance Voronoi	Max Distance County
Columbus County Hospital	Columbus	0.4041	0.5321
CarolinaEast Medical Canter	Craven	0.4103	0.6723
Cape Fear Valley Medical Center	Cumberland	0.3474	0.4275
The Outer Banks Hospital	Dare	0.4421	0.4921
Lexington Memorial Hospital	Davidson	0.2595	0.3701
Thomasville Medical Center	Davidson	0.2708	0.4009
Davie County Hospital	Davie	0.2335	0.3594
Duplin General Hospital	Duplin	0.3173	0.3664
North Carolina Specialty Hospital	Durham	0.1603	0.1884
Durham Regional Hospital	Durham	0.2544	0.2201
Duke University Hospital	Durham	0.2866	0.1627
Heritage Hospital	Edgecombe	0.2830	0.2770
Medical Park Hospital	Forsyth	0.2617	0.2409
Forsyth Medical Center	Forsyth	0.2149	0.2205
North Carolina Baptist Hospitals	Forsyth	0.2673	0.2897
Franklin Regional Medical Center	Franklin	0.3477	0.3657
Gaston Memorial Hospital	Gaston	0.3718	0.3495
Granville Medical Center	Granville	0.2698	0.3195
High Point Regional Health System	Guilford	0.2878	0.3117
Moses Cone Health System	Guilford	0.2798	0.5183
Our Community Hospital	Halifax	0.3889	0.6449
Halifax Regional Medical Center	Halifax	0.2568	0.6867
Harnett Health System Central Campus	Harnett	0.2993	0.5912
Betsy Johnson Regional Hospital	Harnett	0.2767	0.6156
Haywood Regional Medical Center	Haywood	0.4365	0.3654
Park Ridge Hospital	Henderson	0.2735	0.3160
Margaret R. Pardee Memorial Hospital	Henderson	0.3996	0.2955

Hospital	County	Max Distance Voronoi	Max Distance County
Roanoke-Chowan Hospital	Hertford	0.4587	0.5501
Lake Norman Regional Medical Center	Iredell	0.2390	0.1649
Davis Regional Medical Center	Iredell	0.2584	0.2976
Iredell Memorial Hospital	Iredell	0.2364	0.3192
Harris Regional Hospital	Jackson	0.3914	0.4058
Johnston Memorial Hospital	Johnston	0.3217	1.1301
Central Carolina Hospital	Lee	0.3164	1.7894
Lenoir Memorial Hospital	Lenoir	0.2335	3.8134
Carolinas Medical Center - Lincoln	Lincoln	0.2785	4.4729
Angel Medical Center	Macon	0.3964	0.4119
Highlands-Cashiers Hospital	Macon	0.3395	0.5424
Martin General Hospital	Martin	0.2944	5.2598
The McDowell Hospital	McDowell	0.4272	0.4293
Presbyterian Orthopedic Hospital	Mecklenburg	0.0726	0.0933
Carolinas Medical Center - University	Mecklenburg	0.2851	0.0990
Presbyterian Hospital Matthews	Mecklenburg	0.2439	0.1065
Presbyterian Hospital Huntersville	Mecklenburg	0.2368	0.1965
Presbyterian Hospital Mint Hill	Mecklenburg	0.2849	0.1115
Presbyterian Hospital	Mecklenburg	0.0649	0.1978
Carolinas Medical Center - Mercy & Pineville	Mecklenburg	0.2824	0.1902
Carolinas Medical Center / Center for Mental Health	Mecklenburg	0.0856	0.0856
Blue Ridge Regional Hospital	Mitchell	0.3096	2.5992
FirstHealth Montgomery Memorial Hospital	Montgomery	0.2743	1.8326
FirstHealth Moore Regional Hospital	Moore	0.3474	0.5181
Nash General Hospital	Nash	0.3357	0.4492
New Hanover Regional Medical Center	New Hanover	0.4041	0.2755
Onslow Memorial Hospital	Onslow	0.3771	0.3664

Hospital	County	Max Distance Voronoi	Max Distance County
University of North Carolina Hospitals	Orange	0.2727	0.7849
Albemarle Hospital	Pasquotank	0.4361	0.4936
Pender Memorial Hospital	Pender	0.4320	0.4173
Person Memorial Hospital	Person	0.3813	0.2508
Pitt County Memorial Hospital	Pitt	0.3010	0.4872
St. Luke's Hospital	Polk	0.2735	0.2515
Randolph Hospital	Randolph	0.3141	0.3322
Sandhills Regional Medical Center*	Richmond	0.9720	0.4647
FirstHealth Richmond Memorial Hospital	Richmond	0.3764	0.3889
Southeastern Regional Medical Center	Robeson	0.3533	0.4508
Annie Penn Hospital	Rockingham	0.4141	0.4069
Morehead Memorial Hospital	Rockingham	0.2492	0.3782
Rowan Regional Medical Center	Rowan	0.2851	0.3388
Rutherford Hospital	Rutherford	0.5951	0.3479
Sampson Regional Medical Center	Sampson	0.3534	0.4494
Scotland Memorial Hospital	Scotland	0.3474	0.2915
Stanly Regional Medical Center	Stanly	0.2851	0.3588
Stokes-Reynolds Memorial Hospital	Stokes	0.2878	0.2832
Northern Hospital of Surry County	Surry	0.1809	0.3741
Hugh Chatham Memorial Hospital	Surry	0.2682	0.4814
Swain County Hospital	Swain	0.3441	0.5094
Transylvania Community Hospital	Transylvania	0.2577	0.3427
Carolinas Medical Center - Union	Union	0.2824	0.3309
Maria Parham Hospital	Vance	0.3757	0.5535
WakeMed Cary Hospital	Wake	0.2053	0.4491
Duke Health Raleigh Hospital	Wake	0.2755	0.4352
Rex Hospital	Wake	0.2993	0.5323

Hospital	County	Max Distance Voronoi	Max Distance County
WakeMed Raleigh Campus	Wake	0.2479	0.4432
Washington County Hospital	Washington	0.3416	0.3962
Blowing Rock Hospital	Watauga	0.2273	0.2831
Watauga Medical Center	Watauga	0.2898	0.2368
Wayne Memorial Hospital	Wayne	0.2794	0.3243
Wilkes Regional Medical Center	Wilkes	0.2898	0.4050
Wilson Medical Center	Wilson	0.2981	0.2766
Hoots Memorial Hospital	Yadkin	0.2617	0.2449

APPENDIX D - *The Acute Care Bed Need Projections according to Proposed Methodology (Tertiary Care Hospitals excluded)*

Hospital	County	Voronoi Population	Acute Care Days	Number of Licensed Bed (w/o Adjustments)	Adjustments	Number of Licensed Bed	Computed Acute Care Days	Computed Number of Beds	Computed Bed -Licensed Bed
Alamance Regional Medical Center	Alamance	145,870	45,843	182	0	182	81,759	378	196
Alexander Hospital	Alexander	42,840	0	25	0	25	24,011	111	86
Alleghany Memorial Hospital	Alleghany	12,260	2,785	41	0	41	6,872	32	-9
Anson Community Hospital	Anson	26,120	4,152	52	0	52	14,640	68	16
Ashe Memorial Hospital	Ashe	23,850	5,182	76	0	76	13,368	62	-14
Charles A. Cannon, Jr. Memorial Hospital	Avery	17,450	6,433	30	0	30	9,781	45	15
Pungo District Hospital Corporation	Beaufort	27,160	2,259	39	0	39	15,223	70	31
Beaufort County Hospital	Beaufort	40,260	7,987	120	0	120	22,565	104	-16
Bertie Memorial Hospital	Bertie	9,840	1,578	6	0	6	5,515	25	19
Cape Fear Valley - Bladen County Hospital	Bladen	28,170	3,794	48	0	48	15,789	73	25
J. Arthur Dosher Memorial Hospital	Brunswick	31,670	4,630	36	0	36	17,751	82	46
Brunswick Community Hospital	Brunswick	33,420	11,513	60	14	74	18,732	86	12
Mission Hospitals	Buncombe	181,120	186,888	673	0	673	101,516	469	-204
Grace Hospital	Burke	53,070	20,541	162	0	162	29,745	137	-25
Valdese General Hospital	Burke	38,330	11,794	131	0	131	21,484	99	-32
Carolinas Medical Center - NorthEast	Cabarrus	116,800	105,542	447	0	447	65,465	302	-145
Caldwell Memorial Hospital	Caldwell	52,280	17,505	110	0	110	29,302	135	25
Carteret General Hospital	Carteret	48,340	27,483	135	0	135	27,094	125	-10
Frye Regional Medical Center	Catawba	96,540	47,695	209	0	209	54,110	250	41
Catawba Valley Medical Center	Catawba	38,450	39,713	200	0	200	21,551	100	-100
Chatham Hospital	Chatham	86,020	3,341	25	0	25	48,213	223	198
Murphy Medical Center	Cherokee	84,680	8,473	57	0	57	47,462	219	162
Chowan Hospital	Chowan	12,010	6,988	49	0	49	6,731	31	-18
Kings Mountain Hospital	Cleveland	53,070	7,025	72	0	72	29,745	137	65
Cleveland Regional Medical Center	Cleveland	78,850	37,156	241	0	241	44,195	204	-37
Columbus County Hospital	Columbus	48,520	18,581	154	0	154	27,195	126	-28
CarolinaEast Medical Canter	Craven	75,400	77,706	270	37	307	42,261	195	-112
Cape Fear Valley Medical Center	Cumberland	325,150	145,017	487	44	531	182,243	842	311
The Outer Banks Hospital	Dare	21,790	3,634	21	0	21	12,213	56	35
Lexington Memorial Hospital	Davidson	62,870	11,231	94	0	94	35,238	163	69
Thomasville Medical Center	Davidson	72,960	12,900	123	0	123	40,893	189	66
Davie County Hospital	Davie	29,330	1,420	81	0	81	16,439	76	-5

Hospital	County	Voronoi Population	Acute Care Days	Number of Licensed Bed (w/o Adjustments)	Adjustments	Number of Licensed Bed	Computed Acute Care Days	Computed Number of Beds	Computed Bed -Licensed Bed
Duplin General Hospital	Duplin	44,320	11,401	61	0	61	24,841	115	54
North Carolina Specialty Hospital	Durham	93,370	3,248	18	0	18	52,333	242	224
Durham Regional Hospital	Durham	74,240	64,752	316	0	316	41,611	192	-124
Heritage Hospital	Edgecombe	71,970	15,631	101	0	101	40,338	186	85
Medical Park Hospital	Forsyth	61,430	4,906	22	0	22	34,431	159	137
North Carolina Baptist Hospitals	Forsyth	69590	218,898	789	13	802	39,004	180	-622
Franklin Regional Medical Center	Franklin	173070	11,342	70	0	70	97,004	448	378
Gaston Memorial Hospital	Gaston	156570	81,162	372	0	372	87,756	405	33
Granville Medical Center	Granville	41640	8,077	62	0	62	23,339	108	46
High Point Regional Health System	Guilford	269290	67,906	291	16	307	150,934	697	390
Moses Cone Health System	Guilford	175080	192,429	759	18	777	98,130	453	-324
Our Community Hospital	Halifax	41890	52	20	0	20	23,479	108	88
Halifax Regional Medical Center	Halifax	60830	33,056	186	0	186	34,095	157	-29
Harnett Health System Central Campus	Harnett	53760	0	0	50	50	30,132	139	89
Betsy Johnson Regional Hospital	Harnett	34420	27,358	101	0	101	19,292	89	-12
Haywood Regional Medical Center	Haywood	64020	14,217	153	0	153	35,882	166	13
Park Ridge Hospital	Henderson	55190	14,135	62	0	62	30,933	143	81
Margaret R. Pardee Memorial Hospital	Henderson	72070	23,211	193	0	193	40,394	187	-6
Roanoke-Chowan Hospital	Hertford	40870	14,323	86	0	86	22,907	106	20
Lake Norman Regional Medical Center	Iredell	73390	27,321	105	18	123	41,134	190	67
Davis Regional Medical Center	Iredell	43480	16,476	120	-18	102	24,370	113	11
Iredell Memorial Hospital	Iredell	36450	40,708	199	0	199	20,430	94	-105
Harris Regional Hospital	Jackson	28370	18,293	86	0	86	15,901	73	-13
Johnston Memorial Hospital	Johnston	86630	37,952	157	22	179	48,555	224	45
Central Carolina Hospital	Lee	79950	19,687	127	0	127	44,811	207	80
Lenoir Memorial Hospital	Lenoir	73640	46,226	218	0	218	41,274	191	-27
Carolinas Medical Center - Lincoln	Lincoln	24480	15,253	101	0	101	13,721	63	-38
Angel Medical Center	Macon	24340	5,607	59	0	59	13,642	63	4
Highlands-Cashiers Hospital	Macon	15800	919	24	0	24	8,856	41	17
Martin General Hospital	Martin	43610	7,965	49	0	49	24,443	113	64
The McDowell Hospital	McDowell	38780	6,525	65	0	65	21,736	100	35
Presbyterian Orthopaedic Hospital	Mecklenburg	25210	12,803	140	-126	14	14,130	65	51
Carolinas Medical Center - University	Mecklenburg	190840	21,979	130	-36	94	106,964	494	400

Hospital	County	Voronoi Population	Acute Care Days	Number of Licensed Bed (w/o Adjustments)	Adjustments	Number of Licensed Bed	Computed Acute Care Days	Computed Number of Beds	Computed Bed -Licensed Bed
Presbyterian Hospital Matthews	Mecklenburg	102820	30,779	102	12	114	57,629	266	152
Presbyterian Hospital Huntersville	Mecklenburg	77150	17,081	60	15	75	43,242	200	125
Presbyterian Hospital Mint Hill	Mecklenburg	78880	0	0	50	50	44,211	204	154
Presbyterian Hospital	Mecklenburg	47450	154,618	463	76	539	26,595	123	-416
Carolinas Medical Center - Mercy & Pineville	Mecklenburg	134470	61,844	294	36	330	75,369	348	18
Carolinas Medical Center / Center for Mental Health	Mecklenburg	110140	233,864	795	0	795	61,732	285	-510
Blue Ridge Regional Hospital	Mitchell	31680	6,568	46	0	46	17,756	82	36
FirstHealth Montgomery Memorial Hospital	Montgomery	80110	1,835	37	0	37	44,901	207	170
FirstHealth Moore Regional Hospital	Moore	72750	73,264	297	23	320	40,776	188	-132
Nash General Hospital	Nash	109860	56,687	270	0	270	61,575	284	14
New Hanover Regional Medical Center	New Hanover	177440	139,307	647	0	647	99,453	459	-188
Onslow Memorial Hospital	Onslow	157670	33,350	162	0	162	88,372	408	246
Albemarle Hospital	Pasquotank	122620	27,437	182	0	182	68,727	317	135
Pender Memorial Hospital	Pender	45010	5,647	43	0	43	25,228	116	73
Person Memorial Hospital	Person	47590	9,717	50	0	50	26,674	123	73
St. Luke's Hospital	Polk	127990	3,521	45	0	45	71,737	331	286
Randolph Hospital	Randolph	81620	27,782	145	0	145	45,747	211	66
Sandhills Regional Medical Center*	Richmond	15440	11,962	54	6	60	8,654	40	-20
FirstHealth Richmond Memorial Hospital	Richmond	28620	12,731	99	0	99	16,041	74	-25
Southeastern Regional Medical Center	Robeson	105250	60,085	292	0	292	58,991	272	-20
Annie Penn Hospital	Rockingham	50890	13,555	110	0	110	28,523	132	22
Morehead Memorial Hospital	Rockingham	46570	21,894	108	0	108	26,102	121	13
Rowan Regional Medical Center	Rowan	116770	34,559	223	0	223	65,448	302	79
Rutherford Hospital	Rutherford	68390	17,359	129	0	129	38,332	177	48
Sampson Regional Medical Center	Sampson	50010	12,653	116	0	116	28,030	129	13
Scotland Memorial Hospital	Scotland	57660	24,706	97	21	118	32,318	149	31
Stanly Regional Medical Center	Stanly	68730	14,101	97	0	97	38,522	178	81
Stokes-Reynolds Memorial Hospital	Stokes	48540	842	53	0	53	27,206	126	73
Northern Hospital of Surry County	Surry	52600	15,719	100	0	100	29,482	136	36
Hugh Chatham Memorial Hospital	Surry	36570	18,817	81	0	81	20,497	95	14
Swain County Hospital	Swain	12430	1,607	48	0	48	6,967	32	-16
Transylvania Community Hospital	Transylvania	32900	5,829	42	0	42	18,440	85	43
Carolinas Medical Center - Union	Union	76570	40,362	157	0	157	42,917	198	41

Hospital	County	Voronoi Population	Acute Care Days	Number of Licensed Bed (w/o Adjustments)	Adjustments	Number of Licensed Bed	Computed Acute Care Days	Computed Number of Beds	Computed Bed -Licensed Bed
Maria Parham Hospital	Vance	84830	19,892	91	0	91	47,546	220	129
WakeMed Cary Hospital	Wake	134780	38,542	156	0	156	75,543	349	193
Duke Health Raleigh Hospital	Wake	163470	23,215	186	0	186	91,623	423	237
Rex Hospital	Wake	186640	106,947	425	8	433	104,610	483	50
WakeMed Raleigh Campus	Wake	172480	177,318	515	113	628	96,673	446	-182
Washington County Hospital	Washington	15870	1,849	49	-37	12	8,895	41	29
Blowing Rock Hospital	Watauga	9760	585	28	0	28	5,470	25	-3
Watauga Medical Center	Watauga	38530	21,199	117	0	117	21,596	100	-17
Wayne Memorial Hospital	Wayne	115510	60,022	255	0	255	64,742	299	44
Wilkes Regional Medical Center	Wilkes	46450	16,184	120	0	120	26,035	120	0
Wilson Medical Center	Wilson	99170	34,631	294	-96	198	55,584	257	59
Hoots Memorial Hospital	Yadkin	46000	1,069	22	0	22	25,782	119	97

APPENDIX E – *Comparison of Max Distances for Basic Case and Proposals*

Hospital	County	Computed Bed -Licensed Bed			
		Basic	WakeMedProposal	RexProposal	NovantProposal
Alamance Regional Medical Center	Alamance	0.3440	0.3440	0.3440	0.3440
Alexander Hospital	Alexander	0.2784	0.2784	0.2784	0.2784
Alleghany Memorial Hospital	Alleghany	0.1229	0.1229	0.1229	0.1229
Anson Community Hospital	Anson	0.2695	0.2695	0.2695	0.2695
Ashe Memorial Hospital	Ashe	0.2125	0.2125	0.2125	0.2125
Charles A. Cannon, Jr. Memorial Hospital	Avery	0.2258	0.2258	0.2258	0.2258
Pungo District Hospital Corporation	Beaufort	0.6206	0.6206	0.6206	0.6206
Beaufort County Hospital	Beaufort	0.3077	0.3077	0.3077	0.3077
Bertie Memorial Hospital	Bertie	0.2819	0.2819	0.2819	0.2819
Cape Fear Valley - Bladen County Hospital	Bladen	0.4041	0.4041	0.4041	0.4041
J. Arthur Dosher Memorial Hospital	Brunswick	0.1546	0.1546	0.1546	0.1546
Brunswick Community Hospital	Brunswick	0.2350	0.2350	0.2350	0.2350
Mission Hospitals	Buncombe	0.4986	0.4986	0.4986	0.4986
Grace Hospital	Burke	0.2593	0.2593	0.2593	0.2593
Valdese General Hospital	Burke	0.2246	0.2246	0.2246	0.2246
Carolinas Medical Center - NorthEast	Cabarrus	0.1631	0.1631	0.1631	0.1631
Caldwell Memorial Hospital	Caldwell	0.2898	0.2898	0.2898	0.2898
Carteret General Hospital	Carteret	0.3141	0.3141	0.3141	0.3141
Frye Regional Medical Center	Catawba	0.2293	0.2293	0.2293	0.2293
Catawba Valley Medical Center	Catawba	0.2246	0.2246	0.2246	0.2246
Chatham Hospital	Chatham	0.3157	0.3157	0.3157	0.3157
Murphy Medical Center	Cherokee	0.5203	0.5203	0.5203	0.5203
Chowan Hospital	Chowan	0.3198	0.3198	0.3198	0.3198
Kings Mountain Hospital	Cleveland	0.1979	0.1979	0.1979	0.1979
Cleveland Regional Medical Center	Cleveland	0.2599	0.2599	0.2599	0.2599
Columbus County Hospital	Columbus	0.4041	0.4041	0.4041	0.4041
CarolinaEast Medical Canter	Craven	0.4103	0.4103	0.4103	0.4103
Cape Fear Valley Medical Center	Cumberland	0.3474	0.3474	0.3474	0.3474
The Outer Banks Hospital	Dare	0.4421	0.4421	0.4421	0.4421
Lexington Memorial Hospital	Davidson	0.2595	0.2595	0.2595	0.2595
Thomasville Medical Center	Davidson	0.2708	0.2708	0.2708	0.2708
Davie County Hospital	Davie	0.2335	0.2335	0.2335	0.2335
Duplin General Hospital	Duplin	0.3173	0.3173	0.3173	0.3173
North Carolina Specialty Hospital	Durham	0.1603	0.1603	0.1603	0.1603
Durham Regional Hospital	Durham	0.2544	0.2544	0.2255	0.2544
Duke University Hospital	Durham	0.2866	0.2866	0.2866	0.2866
Heritage Hospital	Edgecombe	0.2830	0.2830	0.2830	0.2830
Medical Park Hospital	Forsyth	0.2617	0.2617	0.2617	0.2617
Forsyth Medical Center	Forsyth	0.2149	0.2149	0.2149	0.2149

Hospital	County	Computed Bed -Licensed Bed			
		Basic	WakeMedProposal	RexProposal	NovantProposal
North Carolina Baptist Hospitals	Forsyth	0.2673	0.2673	0.2673	0.2673
Franklin Regional Medical Center	Franklin	0.3477	0.3477	0.3477	0.3477
Gaston Memorial Hospital	Gaston	0.3718	0.3718	0.3718	0.3718
Granville Medical Center	Granville	0.2698	0.2698	0.2698	0.2698
High Point Regional Health System	Guilford	0.2878	0.2878	0.2878	0.2878
Moses Cone Health System	Guilford	0.2798	0.2798	0.2798	0.2798
Our Community Hospital	Halifax	0.3889	0.3889	0.3889	0.3889
Halifax Regional Medical Center	Halifax	0.2568	0.2568	0.2568	0.2568
Harnett Health System Central Campus	Harnett	0.2993	0.2993	0.2929	0.2929
Betsy Johnson Regional Hospital	Harnett	0.2767	0.2767	0.2767	0.2767
Haywood Regional Medical Center	Haywood	0.4365	0.4365	0.4365	0.4365
Park Ridge Hospital	Henderson	0.2735	0.2735	0.2735	0.2735
Margaret R. Pardee Memorial Hospital	Henderson	0.3996	0.3996	0.3996	0.3996
Roanoke-Chowan Hospital	Hertford	0.4587	0.4587	0.4587	0.4587
Lake Norman Regional Medical Center	Iredell	0.2390	0.2390	0.2390	0.2390
Davis Regional Medical Center	Iredell	0.2584	0.2584	0.2584	0.2584
Iredell Memorial Hospital	Iredell	0.2364	0.2364	0.2364	0.2364
Harris Regional Hospital	Jackson	0.3914	0.3914	0.3914	0.3914
Johnston Memorial Hospital	Johnston	0.3217	0.3217	0.3217	0.3217
Central Carolina Hospital	Lee	0.3164	0.3164	0.3164	0.3164
Lenoir Memorial Hospital	Lenoir	0.2335	0.2335	0.2335	0.2335
Carolinas Medical Center - Lincoln	Lincoln	0.2785	0.2785	0.2785	0.2785
Angel Medical Center	Macon	0.3964	0.3964	0.3964	0.3964
Highlands-Cashiers Hospital	Macon	0.3395	0.3395	0.3395	0.3395
Martin General Hospital	Martin	0.2944	0.2944	0.2944	0.2944
The McDowell Hospital	McDowell	0.4272	0.4272	0.4272	0.4272
Presbyterian Orthopaedic Hospital	Mecklenburg	0.0726	0.0726	0.0726	0.0726
Carolinas Medical Center - University	Mecklenburg	0.2851	0.2851	0.2851	0.2851
Presbyterian Hospital Matthews	Mecklenburg	0.2439	0.2439	0.2439	0.2439
Presbyterian Hospital Huntersville	Mecklenburg	0.2368	0.2368	0.2368	0.2368
Presbyterian Hospital Mint Hill	Mecklenburg	0.2849	0.2849	0.2849	0.2849
Presbyterian Hospital	Mecklenburg	0.0649	0.0649	0.0649	0.0649
Carolinas Medical Center - Mercy & Pineville	Mecklenburg	0.2824	0.2824	0.2824	0.2824
Carolinas Medical Center / Center for Mental Health	Mecklenburg	0.0856	0.0856	0.0856	0.0856
Blue Ridge Regional Hospital	Mitchell	0.3096	0.3096	0.3096	0.3096
FirstHealth Montgomery Memorial Hospital	Montgomery	0.2743	0.2743	0.2743	0.2743
FirstHealth Moore Regional Hospital	Moore	0.3474	0.3474	0.3474	0.3474
Nash General Hospital	Nash	0.3357	0.3357	0.3357	0.3357
New Hanover Regional Medical Center	New Hanover	0.4041	0.4041	0.4041	0.4041

Hospital	County	Computed Bed -Licensed Bed			
		Basic	WakeMedProposal	RexProposal	NovantProposal
Onslow Memorial Hospital	Onslow	0.3771	0.3771	0.3771	0.3771
University of North Carolina Hospitals	Orange	0.2727	0.2727	0.2727	0.2727
Albemarle Hospital	Pasquotank	0.4361	0.4361	0.4361	0.4361
Pender Memorial Hospital	Pender	0.4320	0.4320	0.4320	0.4320
Person Memorial Hospital	Person	0.3813	0.3813	0.3813	0.3813
Pitt County Memorial Hospital	Pitt	0.3010	0.3010	0.3010	0.3010
St. Luke's Hospital	Polk	0.2735	0.2735	0.2735	0.2735
Randolph Hospital	Randolph	0.3141	0.3141	0.3141	0.3141
Sandhills Regional Medical Center*	Richmond	0.9720	0.9720	0.9720	0.9720
FirstHealth Richmond Memorial Hospital	Richmond	0.3764	0.3764	0.3764	0.3764
Southeastern Regional Medical Center	Robeson	0.3533	0.3533	0.3533	0.3533
Annie Penn Hospital	Rockingham	0.4141	0.4141	0.4141	0.4141
Morehead Memorial Hospital	Rockingham	0.2492	0.2492	0.2492	0.2492
Rowan Regional Medical Center	Rowan	0.2851	0.2851	0.2851	0.2851
Rutherford Hospital	Rutherford	0.5951	0.5951	0.5951	0.5951
Sampson Regional Medical Center	Sampson	0.3534	0.3534	0.3534	0.3534
Scotland Memorial Hospital	Scotland	0.3474	0.3474	0.3474	0.3474
Stanly Regional Medical Center	Stanly	0.2851	0.2851	0.2851	0.2851
Stokes-Reynolds Memorial Hospital	Stokes	0.2878	0.2878	0.2878	0.2878
Northern Hospital of Surry County	Surry	0.1809	0.1809	0.1809	0.1809
Hugh Chatham Memorial Hospital	Surry	0.2682	0.2682	0.2682	0.2682
Swain County Hospital	Swain	0.3441	0.3441	0.3441	0.3441
Transylvania Community Hospital	Transylvania	0.2577	0.2577	0.2577	0.2577
Carolinas Medical Center - Union	Union	0.2824	0.2824	0.2824	0.2824
Maria Parham Hospital	Vance	0.3757	0.3757	0.3757	0.3757
WakeMed Cary Hospital	Wake	0.2053	0.2053	0.1494	0.2053
Duke Health Raleigh Hospital	Wake	0.2755	0.2755	0.1458	0.2755
Rex Hospital	Wake	0.2993	0.2993	0.1969	0.2077
Rex HollySprings	Wake			0.2900	
Rex Wakefield	Wake			0.2452	
WakeMed Raleigh Campus	Wake	0.2479	0.2479	0.2479	0.2479
Novant HollySprings	Wake				0.2896
Washington County Hospital	Washington	0.3416	0.3416	0.3416	0.3416
Blowing Rock Hospital	Watauga	0.2273	0.2273	0.2273	0.2273
Watauga Medical Center	Watauga	0.2898	0.2898	0.2898	0.2898
Wayne Memorial Hospital	Wayne	0.2794	0.2794	0.2794	0.2794
Wilkes Regional Medical Center	Wilkes	0.2898	0.2898	0.2898	0.2898
Wilson Medical Center	Wilson	0.2981	0.2981	0.2981	0.2981
Hoots Memorial Hospital	Yadkin	0.2617	0.2617	0.2617	0.2617

APPENDIX F – *Percentages of AC Days coming from the Same County*

ID	LegalIdentity	PrimaryName	County AC Days /Total AC Days
1	Alamance Regional Medical Center, Inc.	Alamance Regional Medical Center	0.8739
3	Alleghany County Memorial Hospital, Inc	Alleghany Memorial Hospital	0.8051
5	Carolinas-Anson Healthcare, Inc	Anson Community Hospital	0.9786
6	Ashe Memorial Hospital, Inc	Ashe Memorial Hospital, Inc	0.9420
1012	Charles A. Cannon, Jr. Memorial Hospital, Inc.	Charles A. Cannon, Jr. Memorial Hospital, Inc.	0.7471
7	Beaufort County Hospital Association, Inc	Beaufort County Hospital	0.7361
1028	Pungo District Hospital Corporation	Pungo District Hospital Corporation	0.6176
8	East Carolina Health-Bertie, Inc	Bertie Memorial Hospital	0.9324
10	County of Bladen	Bladen County Hospital	0.8787
1040	Smithville Township	J. Arthur Dosher Memorial Hospital	0.9128
1055	Brunswick Community Hospital, LLC	Brunswick Community Hospital	0.8812
1050	Mission Hospitals, Inc.	Memorial Mission Hospital and Asheville Surgery Center	0.0000
1031	Grace Hospital, Inc.	Grace Hospital, Inc.	0.6374
129	Valdese General Hospital, Inc.	Valdese General Hospital	0.6215
18	CMC-NorthEast, Inc	CMC-NorthEast, Inc	0.6478
1005	Caldwell Memorial Hospital, Inc.	Caldwell Memorial Hosptial, Inc.	0.9300
1009	Carteret County General Hospital Corporation	Carteret General Hospital	0.8029
1010	County of Catawba	Catawba Valley Medical Center	0.7148
1024	Frye Regional Medical Center, Inc.	Frye Regional Medical Center, Inc.	0.4554
1013	Chatham Hospital, Inc.	Chatham Hosptial, Inc.	0.8824
1053	Murphy Medical Center, Inc.	Murphy Medical Center, Inc.	0.6727
1014	East Carolina Health-Chowan,Inc.	Chowan Hospital	0.5011
1015	Cleveland Regional Medical Center	Cleveland Regional Medical Center	0.7996
1042	Cleveland County HealthCare System	Kings Mountain Hospital	0.6745
1016	Columbus Regional Healthcare System	Columbus Regional Healthcare System	0.9279
1017	Craven Regional Medical Authority	Craven Regional Medical Center	0.6741

ID	LegalIdentity	PrimaryName	County AC Days /Total AC Days
1004	Cumberland County Hospital System, Inc.	Cape Fear Valley Medical Center	0.7817
130	The Outer Banks Hospital, Inc.	The Outer Banks, Hospital, Inc.	0.7558
1045	Lexington Memorial Hospital, Inc.	Lexington Memorial Hospital, Inc.	0.9453
132	Community General Health Partners, Inc.	Thomasville Medical Center	0.8289
15	Davie County Emergency Health Corporation	Davie County Hospital	0.8787
16	Duplin General Hospital, Inc	Duplin General Hospital	0.7982
146	North Carolina Specialty Hospital, LLC	North Carolina Specialty Hospital	0.7857
17	Duke University Health System Inc	Durham Regional Hospital	0.5645
13	Duke University Health System, Inc	Duke University Hospital	0.2844
1035	East Carolina Health - Heritage, Inc.	Heritage Hospital	0.7509
1022	Forsyth Memorial Hospital, Inc.	Forsyth Memorial Hospital, Inc.	0.5847
1049	Medical Park Hospital, Inc.	Medical Park Hospital, Inc.	0.5432
145	North Carolina Baptist Hospital	North Carolina Baptist Hospital	0.3558
1023	Louisburg HMA	Franklin Regional Medical Center	0.7157
1030	Gaston Memorial Hospital	Gaston Memorial Hospital	0.8002
1032	County of Granville	Granville Health System	0.7410
1052	The Moses H. Cone Memorial Hosp. Operating Corporation	Moses Cone Health System	0.7570
1038	High Point Regional Health System	High Point Regional Health System	0.6485
149	Kindred Hospitals East, LLC	Kindred Hospital - Greensboro	0.1572
144	Our Community Hospital, Inc.	Our Community Hospital, Inc.	0.9701
1033	Halifax Regional Medical Center, Inc.	Halifax Regional Medical Center, Inc.	0.6947
9	Harnett Health System, Inc	Betsy Johnson Regional Hospital	0.6727
1034	Haywood Regional Medical Ctr., A NC Hospital Authority	Haywood Regional Medical Center	0.8693
1046	Henderson County Hospital Corporation	Margaret R. Pardee Memorial Hospital	0.8251
114	Fletcher Hospital, Incorporated	Park Ridge Hospital	0.6627
135	East Carolina Health	Roanoke Chowan Hospital	0.5064
1039	Iredell Memorial Hospital, Inc.	Iredelll Memorial Hospital, Inc.	0.7626

ID	LegalIdentity	PrimaryName	County AC Days /Total AC Days
12	Statesville HMA, Inc	Davis Regional Medical Center	0.6521
1043	Mooresville Hospital Management Associates, Inc.	Lake Norman Regional Medical Center	0.6806
1060	WestCare, Inc.	Harris Regional Hospital, Inc.	0.4730
1041	Johnston Memorial Hospital Authority	Johnston Memorial Hopspital	0.8667
1011	Amisub of North Carolina	Central Carolina Hospital	0.7296
1044	Lenoir Memorial Hospital, Inc.	Lenoir Memorial Hospital, Inc.	0.7593
1057	Lincoln Health System	Carolinas Medical Center-Lincoln	0.7925
1027	Angel Medical Center, Inc.	Angel Medical Center, Inc.	0.8880
1036	Highlands-Cashiers Hospital, Inc.	Highlands-Cashiers Hospital, Inc.	0.3775
1048	Williamston Hospital Corporation	Martin General Hospital	0.8303
131	The McDowell Hospital, Inc.	The McDowell Hospital	0.9505
1008	Charlotte Mecklenburg Hospital Authority	Carolinas Medical Center - University	0.8032
117	Presbyterian Hospital	Presbyterian Hospital	0.7459
118	The Presbyterian Hospital	Presbyterian Hospital Huntersville	0.6817
1006	Mercy Hospital	Carolinas Medical Center Mercy/Pineville	0.5983
1054	Carlotte-Mecklenburg Hospital Authority	Carolinas Medical Center/Center for Mental Health	0.5925
119	Presbyterian Medical Care Corp.	Presbyterian Hospital Matthews	0.5520
120	Presbyterian Orthopaedic Hospital, LLC	Presbyterian Orthopaedic Hospital	0.5419
102	Charlotte Mecklenburg Hospital Authority	Carolinas Rehabilitation	0.4918
142	Blue Ridge Hospital Systems, Inc.	Spruce Pine Community Hospital	0.5440
1029	Blue Ridge Hospital Systems, Inc.	Blue Ridge Regional Hospital, Inc.	0.5440
1019	FirstHealth of the Carolinas, Inc.	FirstHealth Montgomery Memorial Hospital	0.9133
1020	FirstHealth of the Carolinas	FirstHealth Moore Reg. Hosp. and Pinehurst Treatment Center	0.4574
112	Nash General Hospital	Nash General Hospital	0.5877
1001	LifeCare Hospitals of North Carolina, LLC	LifeCare Hospitals of North Carolina	0.2088
148	New Hanover Regional Medical Center	New Hanover Regional Medical Center	0.5038
143	Onslow Memorial Hospital	Onslow Memorial Hospital	0.9369

ID	LegalIdentity	PrimaryName	County AC Days /Total AC Days
128	University of North Carolina Hospitals at Chapel Hill	University of North Carolina Hospitals	0.2066
2	Albemarle Hospital Authority	Albemarle Hospital	0.5156
115	Pender Memorial Hospital	Pender Memorial Hospital, Inc.	0.7395
116	Person Memorial Hospital - Roxboro	Person Memorial Hospital	0.8375
113	Pitt County Memorial Hospital, Inc.	Pitt County Memorial Hospital	0.3961
105	St. Luke's Hospital, Inc.	St. Luke's Hospital	0.7129
134	Randolph Hospital, Inc.	Randolph Hospital, Inc.	0.8977
1021	FirstHealth of the Carolinas, Inc.	FirstHealth Richmond Memorial Hospital	0.8667
138	Hamlet HMA, Inc.	Sandhills Regional Medical Center	0.7087
110	Southeastern Regional Medical Center	Southeastern Regional Medical Center	0.8696
4	The Moses H Cone Memorial Hospital Operating Corp	Annie Penn Hospital	0.8599
1051	Morehead Memorial Hopital	Morehead Memorial Hospital	0.7534
137	Rowan Regional Medical Center, Inc.	Rowan Regional Medical Center	0.8520
139	Rutherford Hospital, Inc.	Rutherford Hospital, Inc	0.9123
107	Sampson Regional Medical Center, Inc.	Sampson Regional Medical Center	0.7997
108	Scotland Memorial Hospital, Inc.	Scotland Memorial Hospital and Edwin Morgan Center	0.5515
111	Stanly Regional Medical Center	Stanly Regional Medical Center	0.7528
109	Stokes-Reynolds Memorial Hospital, Inc.	Stokes-Reynolds Memorial Hospital, Inc.	0.8389
147	Northern Hospital District of Surry County	Northern Hospital of Surry County	0.8043
1037	Hugh Chatham Memorial Hospital, Inc.	Hugh Chatham Memorial Hospital, Inc.	0.3873
1059	WestCare, Inc.	Swain County Hospital	0.6797
133	Transylvania Community Hospital, Inc.	Transylvania Community Hospital, Inc.	0.8974
1007	Union Memorial Regional Medical Center, Inc.	Carolinas Medical Center - Union	0.7265
1047	Maria Parham Medical Center, Inc.	Maria Parham Medical Center	0.5418
123	WakeMed	WakeMed Cary Hospital	0.8522
136	Rex Hospital	Rex Hospital	0.8093
14	Duke University Health System, Inc	Duke Health Raleigh Hospital	0.7364

ID	LegalIdentity	PrimaryName	County AC Days /Total AC Days
124	WakeMed	WakeMed	0.6810
121	CAH Acquisition Company #1, LLC	Washington County Hospital	0.8041
11	Blowing Rock Hospital	Blowing Rock Hospital	0.7202
125	Watauga Medical Center, Inc.	Watauga Medical Center, Inc.	0.4981
122	Wayne Memorial Hospital, Inc.	Wayne Memorial Hospital, Inc.	0.8673
126	WRMC Hospital Operating Corporation	Wilkes Regional Medical Center	0.9765
127	Wilson Medical Center	Wilson Medical Center	0.7552
1056	Hoots Memorial Hospital, Inc.	Hoots Memorial Hospital, Inc.	0.7821

APPENDIX G – *Matlab Codes* to Calculate the Maximum Distance and Voronoi Population*

```
%Maximum Distance Calculation
for i=1:114
Hospitali=[Hospital(i,1) Hospital(i,2)]
dt=DelaunayTri(Hospital)
[V,R]=voronoiDiagram(dt)
c=R{i}
V1=[V(c,1) V(c,2)]
d=sqrt(sum((ones(size(c,2),1)*Hospitali-V1).^2,2))
max(d)
P(i,1)=max(d)
end
```

```
%Calculation of Voronoi Population
for i=1:114
Hospitali=[Hospital(i,1) Hospital(i,2)]
dt=DelaunayTri(Hospital);
[V,R]=voronoiDiagram(dt);
c=R{i};
V1=[V(c,1) V(c,2)];
V1=flipud(V1);
V1=[V1(:,:);V1(1,:)]
SumPop=0;
for j=1:1558
   XY=CenTr{j}
[CenTrx, CenTry]=polybool('intersection',XY(:,1),XY(:,2),V1(:,1),V1(:,2))
A1=polyarea(CenTrx,CenTry)
A2=polyarea(XY(:,1),XY(:,2))
frac=A1/A2
InterPop(j,1)=frac*Pop(j,1)

end
InterPop(isnan(InterPop))=0
SumPop=sum(InterPop)
VorPop(i,:)=SumPop
end
```

*Some of the calculations done manually as mentioned in the body part of the Thesis.