MODELING PATIENT ACCESS TO POINT-OF-CARE DIAGNOSTIC RESOURCES IN A HEALTHCARE SMALL-WORLD NETWORK IN RURAL ISAAN, THAILAND

by

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DEDICATION

I dedicate this thesis to my parents Sara and Tom Ferguson.

My mother because she always told each of her children she loved them the most, and meant it every time. She shared with me her love of books, which inspired me to be creative and thoughtful.

My father because through his example I have learned the meaning of real hard work and dedication.

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LIST OF ABBREVIATIONS

OSM	OpenStreetMaps
POCT	Point-of-care Technologies
SNA	Social Network Analysis
SD	Standard Deviation
SWN	Small-world Networks

ABSTRACT

Rapid and accurate diagnoses are important because they drive evidence-based care in health systems. Point-of-care technologies (POCT) can aid in diagnosis by bringing advanced technologies out of hospital or clinical settings and closer to the patients. Health networks are constrained by natural connectivity in the interactions between geography of resources and social forces. Using a geographic information system (GIS) we can understand how populations utilize their health networks, visualize their inefficiencies, and model alternatives. This project focuses on cardiac care resource in rural Isaan, Thailand. A health access model was created using ArcGIS Network Analyst 10.1 from data representing aggregated population, roads, health resource facilities, and diagnostic technologies. This model was used to quantify current cardiac health access and improve upon that access using both widespread and resource limited strategies. Sensitivity analysis revealed that altering travel speeds of roads has a large effect on the calculation of health access. Results indicated that having diagnostic technologies closer to population allowed the streamlining of care paths. The model allowed for comparison of the effectiveness of the implementation strategies. This model was created to help put the benefit of adopting POCT within health networks within perspective. Additionally it can help evaluate these alternatives diagnostic placement strategies as compared to the current health access and evaluate the relative costs and benefits.

CHAPTER 1: INTRODUCTION

The purpose of this project is to demonstrate how a model can quantify access to cardiac care within a health network and evaluate ways to improve that access. This study focuses on an area within the northern Isaan region in Thailand to demonstrate this model; however it was created to be applied to any geographic location. This project focuses on understanding how point-of-care technologies (POCT) can improve patient access to care within health networks. POCT are novel technologies used to obtain diagnostic information at or near the patient site of care (Kost, Tran, and Louie 2002). POCT affords diagnostic information in places where it previously would not be available, thus streamlining decision-making at the point of need.

This project builds upon the research by Kost et al. (2010) which surveyed health facilities within Isaan, Thailand for cardiac diagnostic support. This project adds to that research by using a GIS to understand how different implementation strategies for POCT can improve health access for a population. Table 1 defines some of the major concepts used in this project. These are explained further in the literature review (Chapter 2).

Table 1 Definition of Core Concepts

Concept	Description
Health Networks	The resources and infrastructure that allow people to understand and care for their health.
Small-world networks	Represent the natural connectivity by which the population utilizes their health networks.
Point-of-Care Technologies	Medical diagnostic testing at or near the patient site of care. Due to the miniaturization of laboratory tests, diagnostic information can be obtained in non-traditional locations.
Health Access	Defined as the ability of populations to utilize their health resources. In this study it mainly refers to the physical access, as how a person would travel to reach their health resources.

1.1 Motivation

A geographic information system (GIS) can be used to provide a framework to understand how populations utilize their health networks. Health access studies quantify population access to health resources, visualize inefficiencies, and model alternative scenarios (Clark et al. 2012; Coffee et al. 2012; Ranisinghe et al. 2012). These studies are often limited because they either do not a) identify social pressures of a health system (e.g, cultural health related decisions) or b) focus on how diagnostic information is obtained.

Health networks are complex systems whose properties are not explained by the sum of their parts and are often defined by the natural connectivity that arises from their element interactions (Luke and Stamatakis 2012). Health networks can be thought of as small-world networks (SWN), which are not completely random or regularly connected systems (Wattz and Strogatz 1998), and may not be efficient in terms of the urgent health of its populations. This study shows that a GIS can be used to identify the SWN that exist within health networks, and to model inefficiencies and help understand how to make them more efficient.

POCT have been implemented in national disaster caches for disaster preparedness (Curtis et al. 2013), emergency settings for care optimization (Lewandrowski and Lewandrowski 2013), and low resource settings (Garcia et al. 2013; Mabey et al. 2012). In rural settings, POCT are often the only alternative to conventional laboratory tests. POCT allow populations to access diagnostic information in places where they previously would not be available.

POCT result from the miniaturization of conventional laboratory diagnostic tests into portable forms. Many POCT are defined by what is called the Affordable, Sensitive, Specific, User-friendly, Rapid/robust, Equipment-free, and Deliverable (ASSURED) criteria (Peeling and Mabey 2010). The most prevalent POCT are glucose meters, which allow users to monitor their diabetes and self-administer treatment. Effectively, the ASSURED qualities allow POCT to be used in non-laboratory settings, by non-technical staff, and without infrastructure like in-wall electricity which allows them to be used in a wide range of environments.

Kost et al. (2010) attempted to quantify SWN relationships for cardiac support in health facilities in Northeastern Isaan, Thailand. Their study revealed isolated regions that did not have adequate support for their populations. They suggested several placement strategies for POCT that would improve patient outcomes. While the study was useful for understanding the SWN, it did not attempt to quantify population access to these diagnostic resources nor model how the recommended placement strategies would affect this access.

GIS provides the ability to quantify how to effectively implement POCT in health networks. If implemented correctly POCT have the ability to help streamline decision making. This can a) improve patient outcomes, b) save resources including money and time, and c) ensure that the health networks are sufficiently robust for a disaster or emergency event. This project demonstrates how a GIS can be used to quantify health access and help make decisions on how to integrate POCT.

The goal of this project is to create, evaluate, and utilize a spatial model that can be used to improve health networks by quantifying pathways of individuals towards a diagnosis and then care. This model was evaluated within the study area used in the Kost et al. (2010) study focusing on the diagnosis and care of individuals with acute myocardial infarction (heart disease). The goals are:

- To build and evaluate a workable model that defines health access.
- Use the model to define the current health access to cardiac care within a study area used in the Kost et al. (2010) study.

- Use the model to evaluate implementation strategies that improve health access to cardiac care.
- Define means to evaluate the outcomes of the implementation strategies against current access.

The following Chapters discuss a) the literature and background that inspired the project, b) the study area, data, and methods, c) the results, d) critical analysis of the data used and methods used, and e) how the spatial model can be used for decisions making within health networks. The end result of this project seeks to a) understand the benefit that POCT can provide within SWN and b) quantify this benefit such that it can be put into perspective to the technology integration costs.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

This chapter provides an overview to several themes relevant to this study. It begins by describing the role of GIS in public health. It then evaluates previous methods of quantifying health networks and explores how a GIS can be used to improve upon those methods using SWN analysis. Additionally, it discusses how POCT are well-suited to be integrated into SWN to improve health access. The chapter finishes by critically evaluating previous GIS based attempts to quantify health access.

2.1 GIS in Public Health

Modern GIS applications in public health can be sorted into four categories (Nykiforuk and Flaman 2011):

a) disease mapping - the compilation and tracking of data on the incidence, prevalence, and spread of disease
b) risk analysis - which examine the exposure to hazardous environments,
c) community health profiling - the mapping of information pertaining to the health of a population in a community, and
d) access and planning - which is ability of the community to use health services

This project focuses on using GIS to quantify and improve access to health resources.

Health access can be described as people's ability to use health services when they are needed (Cromley and McLafferty 2012). Health access can further be sorted into five dimensions of access:

a) availability, how the supply of services meets the population needs,
b) accessibility, which deals with physical access, including travel time and cost,

c) accommodation, which focuses on how the services are oriented to the consumer (waiting times, hours of operation),
d) affordability, which has to do with the cost of services, and
e) acceptability, or the patient's opinion of the services.

This project focuses on the physical accessibility of resource, particularly how the availability of diagnostic resources can shed light on inadequacies within a health network.

2.2 Social Network Analysis & Physical Network Analysis

Luke and Stamatakis (2012) discussed the complexity of public health systems, meaning the outcomes of a system are often greater than the sum of its individual parts. The authors point out that common medical investigations are inadequate because they break down and study systems by their individual components. Luke and Stamatakis (2012) go on to state that evaluating a single component will not help understand the system as a whole and suggest network analysis as a means to support more appropriate research.

Social Network Analysis (SNA) emphasizes the complexity of health systems and attempts to understand the relationships between actors within a system (Blanchet and James 2012). These methods have become a recent trend in medical system research (Chambers et al. 2012) underscored by the creation of a journal in 2012 entitled *Network Modeling Analysis in Health Informatics and Bioinformatics.* However, SNA is inadequate to describe health networks because the studies often ignore the role of geography in the relationships between people and their health resources.

2.3 Small-world networks and Point-of-Care Technologies

Watts and Strogatz (1998) argue that conventional network analysis is inadequate because it assumes the connected topology of biological and social systems are either completely random or completely regular. Instead, they lie somewhere in the middle, and can be considered a ‘small-world’ as popularized by a 1969 play “Six Degrees of Separation” (Watts and Strogatz 1998). This concept asserts that all people are connected through at the most six social jumps among friends, colleagues, and acquaintances. SWN are not limited to social connections and have been used to describe physical networks including electrical, road, and health networks.

SWN are visually defined as an interpolation between regular and random networks. (Figure 1) A ring lattice with *n* vertices and *k* edges per vertex is constructed. In a regular network, edges connect vertices to their immediate neighbors. In a random network, neighbors are no longer connected as often and instead long range jumps are made to random vertices. A SWN lies somewhere between a regular and random network; where most neighbors are connected with a few long range exceptions. This creates short-cuts that not only affect their immediate vertices, but neighbors as well. In this project, we do not focus on the mathematical framework but instead apply a theoretical framework to evaluate the healthcare small-world phenomenon to a health system.

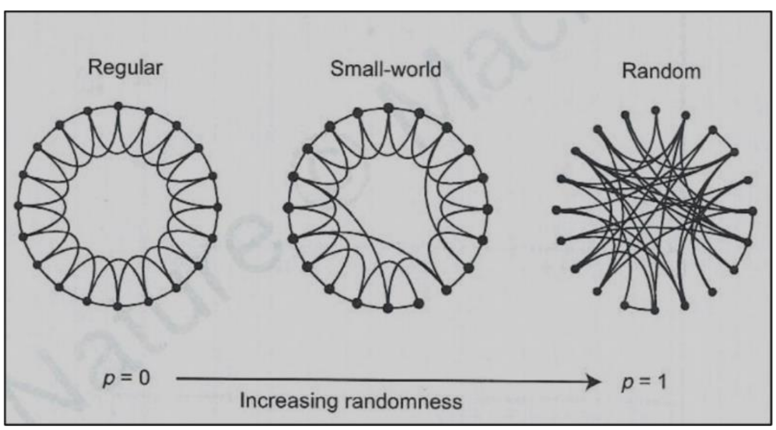

Figure 1 Visualizes how a small-world network differs from a regular (left) and random (right) network. (Figure taken from Watts and Strogatz 1998)

Healthcare SWN evolve naturally due to “geographic terrain, rural locations of community hospitals, and fastest routes for ambulances” (Kost, Yu, and Tran 2010, p. 97). POCT are integral for improving the healthcare SWN because they allow information to be obtained at the site of care allowing key information to serve people faster. (Kost 2012) The added benefit of introducing POCT into health networks is that it allows them to be more robust during emergencies, where diagnostic information can be obtained even with infrastructure damaged or severed (Kost 2012).

2.4 POCT SWN Analysis

A study was performed to understand how rural emergency departments of low-resource community hospitals diagnose acute myocardial infarction (Kost et al. 2010). That project sought to understand whether a SWN existed within the Northern Isaan region in Thailand. Health professionals were surveyed on cardiac testing equipment services, point-of-care resources, and health care delivery systems. To understand ambulance travel times between hospitals, regional topographic maps were presented to emergency medical service personnel who indicated transportation routes used to regional hospitals.

The study revealed isolated regions with large populations that were far away from diagnosis and treatment. For care of acute myocardial infarction, patients must be transferred to regional hospitals, which can be as much as four hours away. Inefficient diagnoses delay the decisions to route patients to care. The study concluded that having POCT integrated into different levels of hospital infrastructure (i.e. smaller facilities that are closer to populations), will speed patient diagnosis and thus efficient transfer to locations of care.

The Kost et al. (2010) study is inadequate for two reasons. The first is because it did not attempt to understand population access to the diagnostic resources or the role they play to the eventual care of individuals. Ensuring that access is quantified either through travel time or distance from the place of the individual is important because it ensures proper accounting for the onset of the illness. The second reason is that while the study offers recommendations for new POCT resources, it does not offer a means to model their effects. A GIS is used in this study to model population access to diagnostic resources within the SWN and evaluate alternative POCT placement schemes.

2.5 Modeling Health Access

Network analysis is used to understand the cost, delivery, and accumulation of resources between links of given connections (Bolstad 2011). GIS health access studies use three data sources: population, health resources, and road networks. Population data are often obtained from country census and aggregated to centroids. Roads are used to represent how people can travel within the health network. Roads are differentiated from each other based on their qualities, such as number of lanes, road quality, or type. From those qualities average or maximum travel speeds are estimated and used to determine distance travel time and distance to nearest facilities. The methods used to locate the closest facility differ from study to study.

2.5.1 Raster-Based Approach

Many health access studies use raster-based methods (Clark et al. 2012; Coffee et al. 2012; Ranisinghe et al. 2012) where any path within the raster is potentially available for travel. Each cell is assigned a travel cost, usually based on the type of road that passes through it. If several roads pass through a single cell, the investigator then decides which better represents that cell travel cost. A path is selected based on the route that costs the least.

2.5.2 Vector-Based Approach

The other type of health access investigation employs a vector-based approach (Brabyn and Skelly 2002, Schuurman-et al. 2006; Owen, Obregon, and Jacobsen 2010). In a vector approach travel is only allowed along the roads. A travel cost is calculated based on the travel speeds assigned to the roads. Additional travel costs and elements can be added such as turns, stoplights, and one-way streets. The final route is selected by which combination of roads costs the least to travel by.

2.5.3 Comparing Vector- and Raster-Based Approaches

Delamater et al. (2012) discuss the nuances of the two approaches by exploring a single facility access study using both vector- and raster-based approaches. The main problem with raster-based studies is that the unique topology of the road networks is lost through the coarse representation in the raster cell. Additionally the raster based approach proved more sensitive when travel speeds were altered. The result of the study proved that although both approaches could provide useful outputs, the vector based method may be more appropriate for representing access.

2.6 Limitation of Previous Health Access Studies

One of the simplest ways to quantify health access is to determine the straight line, or as the crow flies, distances. Jordan et al. (2004) compared straight-line distances to drive-time from urban and rural areas in South West England. The study concluded that although straight-line distances correlated with health access in urban areas, drive-time is a more accurate measure for rural areas.

Brabyn and Skelly (2002) performed one of the first investigations of physical access of the local population to New Zealand hospitals using network analysis. In the study, populations were aggregated to census centroids. Then the closest facility to each centroid was selected along major road networks. Importantly, the analysis did not evaluate the available diagnostic or care resources of these hospitals. Although a hierarchy was used to indicate differing levels of capabilities of health facilities, the study did not classify how individual ailments likely would be handled within the health networks.

More in-depth studies have been performed on health access to individual ailments. Clark et al. (2012), Coffee et al. (2012), and Ranisinghe et al. (2012) all studied cardiac resources in Australia using a raster based approach. Clark et al. (2012) and Coffee et al. (2012) used the Cardiac Accessibility and Remoteness Index of Australia (Cardiac ARIA) to understand access to cardiac supplies for the population before and after cardiac events. Cardiac ARIA models access to key medical services by road ambulance in an acute cardiac event. In contrast, Ranisinhe et al. (2012) measured access to two different intervention techniques for acute myocardial infarctions.

These three studies focused on the access to care resources for acute myocardial infarction. They represent a more focused health access study which looks at an individual ailment within a health network. The studies did not look into how the diagnosis of acute myocardial infarction would occur, thus they provide no means to judge the efficacy of that aspect of the care pathway. Understanding how a condition is first diagnosed and then cared for will lead to a unique insight which may inform decision making on how to improve the health network.

2.7 Summary

Previous investigations point to the use of network analysis to accurately models health access using both physical and social forces of health networks. Health access studies have been used to model and improve health networks but they often do not focus on the role of diagnostic technology. POCT presents a unique tool because it can be easily implemented in new locations. Accurately evaluating its role in health access may reveal insights on effectiveness of integration strategies. This project models the role of POCT within an area in Isaan, Thailand to demonstrate the benefit of adopting POCT within health networks.

CHAPTER 3: METHODOLOGY

This project used a spatial model to define a population's access to cardiac support and how that access can be improved through POCT. The model defines health access by quantifying how an individual would travel from a place of origin to a location of diagnosis and then to a location of care. This process involves four data types: a) populated places, which define where individuals originate from, b) roads, which define how an individual would travel to locations of diagnosis and care, c) health resource facilities, which define the locations of diagnosis and care, and d) cardiac diagnostic resources, or how an individual would obtain a diagnosis for acute myocardial infarction.

This model used two steps to calculate health access, which are summarized in Figure 2. The first step involves calculating the travel time along the road network from populated places to nearest diagnostic facilities. The second step calculates the travel time from the diagnostic facility to nearest location for cardiac care, in this case Srinagarind Hospital. Srinagarind Hospital was selected because it contains the only available cardiac care support in the region. To estimate total health access the travel time from population center to diagnosis is added to the travel time from diagnosis to Srinagarind hospital.

This study first performed a sensitivity analysis to understand how variations in the modeling method affect the calculation of health access. Second, it quantified the current health access according to the resources surveyed by the Kost et al. (2010) study. Third, to improve health access the study evaluated two themes of POCT implementation strategies. The first implementation strategy looks into how a widespread POCT integration would affect health access, the second looks into how a limited resource strategy would affect health access.

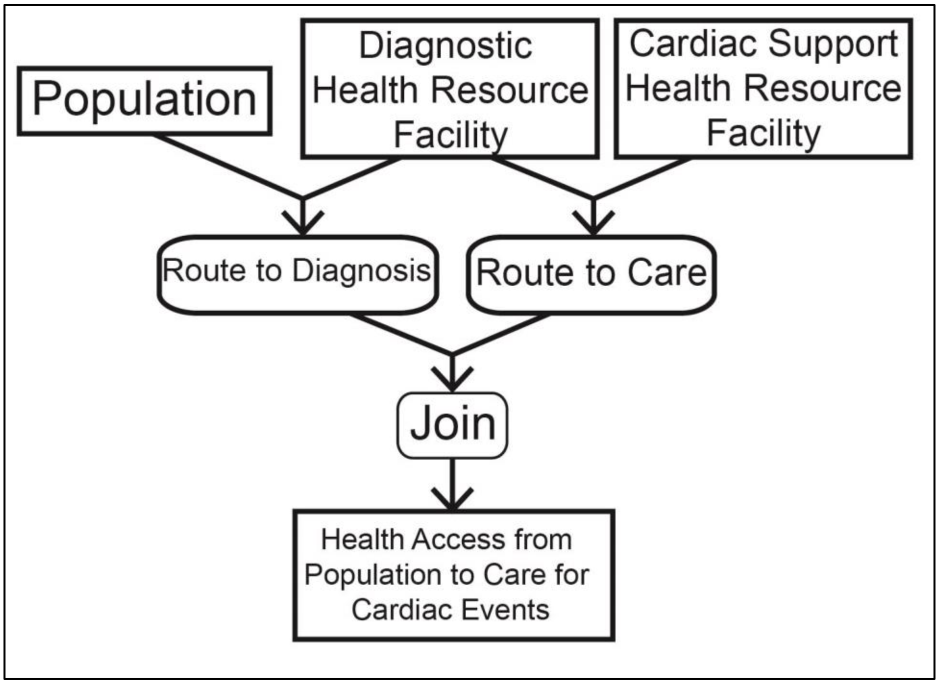

Figure 2 Two-step health access calculation

The following methods section discusses a) the study area used in this investigation, b) the data sources, c) network creation and sensitivity analysis, d) current health access calculation, and e) new implementation strategies.

3.1 Study Area

Thailand was selected as the study area which was previously investigated using paper-based surveys by the researchers in the Kost et al. 2010 study. Thailand, a member of the Association of Southeast Asian Nations (ASEAN), borders Cambodia, Malaysia, Myanmar and Laos. Thailand has a population of approximately seventy million and represents about 11 percent of the total population of ASEAN countries. Thailand consists of seventy seven provinces. The Isaan region, often referred to simply as the Northeast region of the country, had 21,305,000 people in 2010 and is considered to contain the country's most rural and poorest areas.

Figure 3 shows the Isaan region which consists of twenty provinces, eight of which are used in this project. The provinces of Bueng Kan, Sakhon Nakhon, and Nakhon Phanom make up the main study area, where individuals will originate from**.** The provinces of Nong Khai, Udon Thani, Kalasin, and Mukdahan border the main study area and are included because individuals must travel through these provinces to reach Khon Kaen. Khon Kaen province is the second largest province in Isaan and has one of the larger cities in the region containing Srinagarind Hospital, the only location of cardiac care in the region. Additionally these provinces may contain health resource facilities that are closer to populated places than the ones in the main study area. The other twelve provinces are not used in this study.

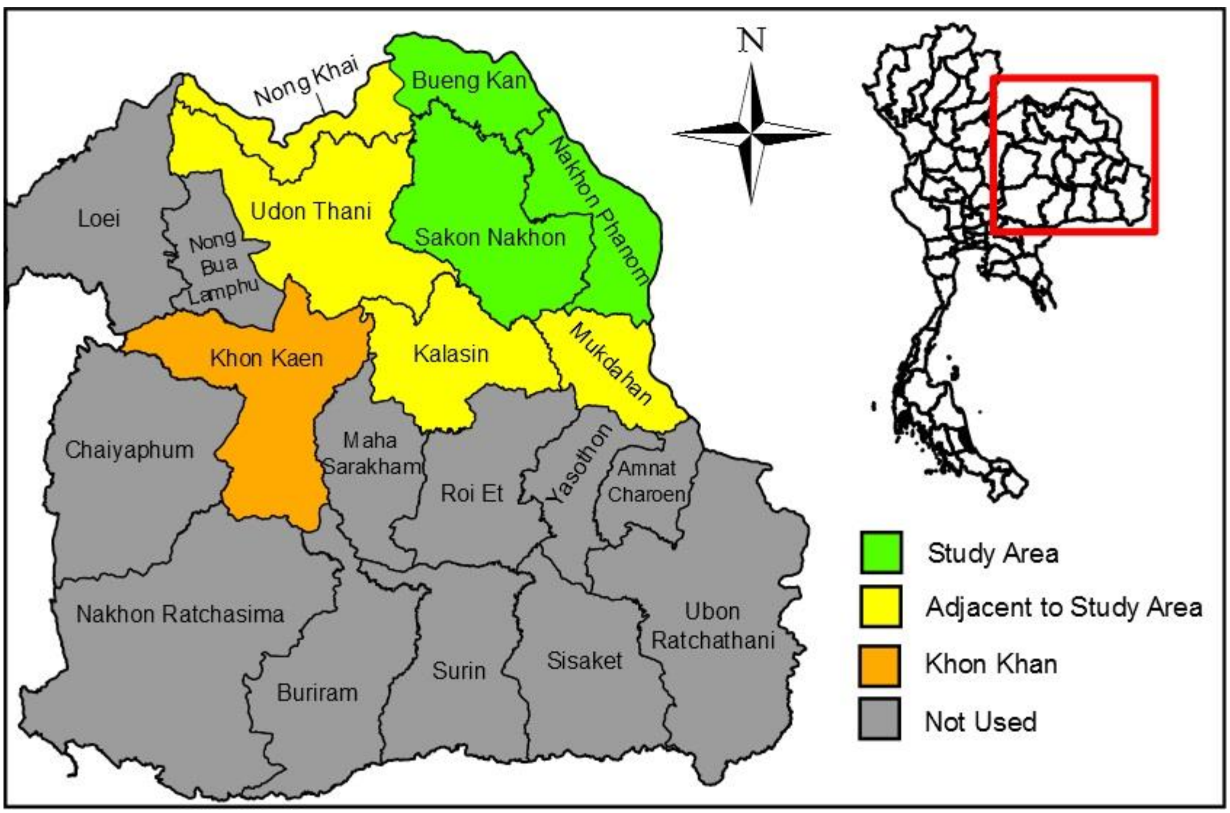

Figure 3 Location of the study area used in this project as compared to the Isaan region

The study area consists of Bueng Kan, which has a size of 4,305 square miles and a population of 362,754; Sakhon Nakhon, a size of 9,606 square miles and a population of

941,810; and Nakhon Phanom, a size of 5,513 square miles and a population of 583,726. Bueng Kan came into existence in 2011 after it was separated from its neighbor Nong Khai (Law 2014).

3.2 Data

Four data sources were used to represent roads, health resource facilities, diagnostic technology locations, political boundaries, and populated places within the study area. Table 2 provides an overview of these data and their sources. Before analysis, all data was projected to the WGS 1984, UTM 47N, which is suitable for use for most of Southeast Asian countries including Thailand.

Table 2 Data sources

Data Name	Theme/Topic	Description	Date Obtained
OpenStreetMap http://www.openstreetmap.org/	Roads and populated places	User submitted open data that emphasizes local knowledge. Contains both line and point data with attributes.	Downloaded May 29th, 2014
MapMagic 2013: Thailand http://www.thinknet.co.th/	Health resource facilities	Proprietary point data collected and sold by a Thai based company.	Assumed to represent the facilities that exist as of 2013.
Global Administrative Areas http://www.gadm.org/	Thailand province and amphoe boundaries	Lines representing political boundaries. Note: Bueng Kan was established in 2011 and the new boundary was added manually.	Downloaded May 29th, 2014
Kost et al. 2010	Diagnostic technology locations	Resources for available cardiac diagnostic resource were surveyed in Isaan Region. Contains attributed point data.	Collected throughout 2009 and 2010.

3.2.1 Population Aggregations

The model used population aggregation points, henceforth referred to as populated places, to represent where individuals may originate when they have a cardiac event. Since data about the distribution of population in the study area was not otherwise available, OpenStreetMap (OSM) data on populated places was used. OSM places represent populated settlements including cities, towns, villages, and suburbs. Places found within the main study are described according to OSM definition in Table 3, along with estimated populations, and number found within the study area. Although the OSM places are most likely not all the population centers in all provinces, they are assumed, for this demonstration, to be a sufficient representation of the population distribution in the provinces.

Table 3 OpenStreetMap populated place descriptions
(Descriptions modified from OpenStreetMap places metadata)

Type	Description	Population Estimate	Count
City	Largest urban settlement in province.	Usually has more than 100,000 people	1
Suburb	A distinct section of an urban settlement.	Unknown population	1
Town	A second tier urban settlement of local importance.	More than 10,000	5
Village	A smaller distinct settlement, smaller than a town.	Less than 10,000	1303
Hamlet	A smaller rural community	100 to 200 people	83

Populated places are summarized by province and type in Table 4 and illustrated in Figure 4. For this study, a place's population was estimated according to OSM's descriptions. Total estimate population was 82 percent of the 2010 Thai Census population. Province estimates were 95 percent of 2010 Thai Census for Bueng Kan, 81 percent for Sakhon Nakhon, and 75 percent for Nakhon Phanom.

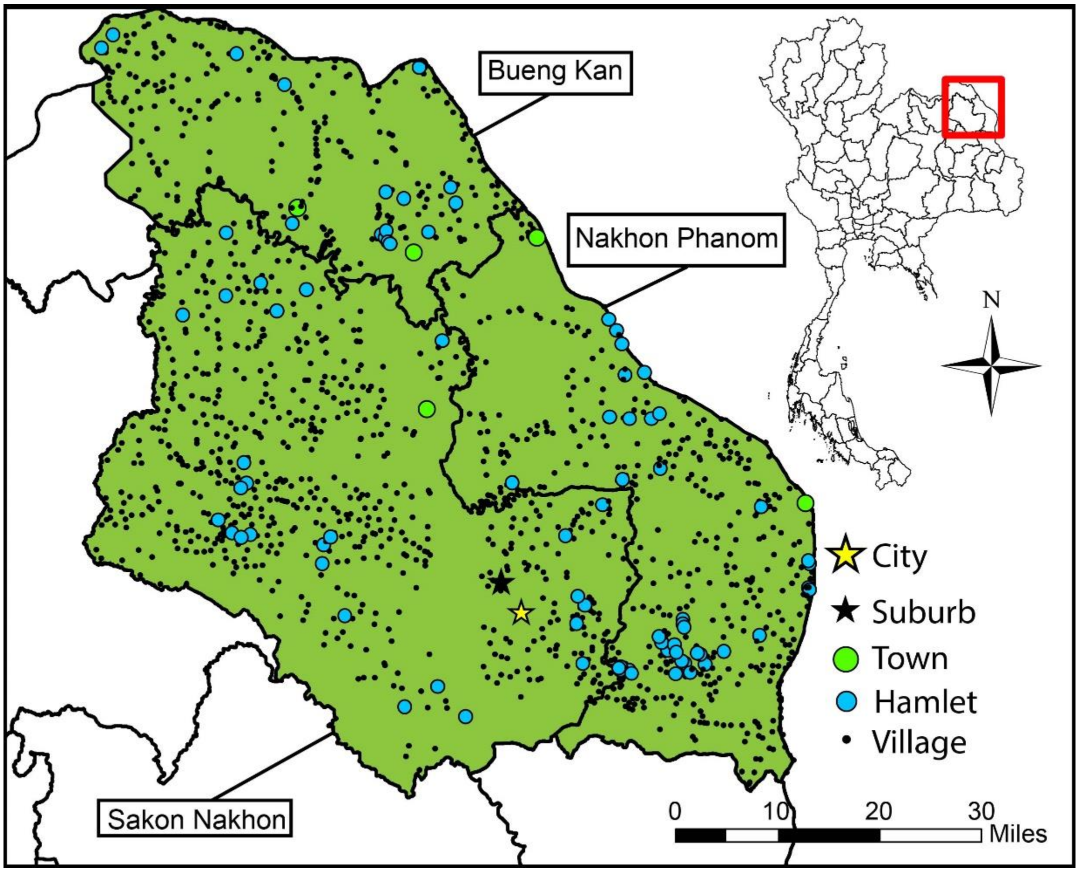

Figure 4 OpenStreetMap aggregated population places

Table 4 Study area populated place quantities and estimated populations

	Bueng Kan		**Sakhon Nakhon**		**Nakhon Phanom**	
Type (Population Estimate)	Quantity	Estimated Population	Quantity	Estimated Population	Quantity	Estimated Population
City (100,000)	0	0	1	100,000	0	0
Suburb (100,000)	0	0	1	100,000	0	0
Town (20,000)	2	40,000	1	20,000	2	40,000
Hamlet (200)	17	34,000	27	5,400	39	7,800
Village (1,500)	271	271,000	641	641,000	391	391,000
Total	290	345,000	671	766,400	432	438,800

3.2.2 Health Resource Facilities

Health resource facilities were obtained from MapMagic 13, a product developed by THiNKNET (www.thinknet.co.th), a company based in Thailand. MapMagic 13 is a mapping application that allows users to visualize and analyze marketing, logistics, and business geographic data in all seventy-seven Thailand provinces. MapMagic 13 has two designations for health resource facilities: hospitals, which tend to be larger facilities with more robust diagnostic and care capabilities, and health promotion hospitals, which represent smaller hospitals including dentist offices and clinics. MapMagic does not provide much detail on the designations; examining the health promotion hospitals in more detail reveals that they include dentist offices and private clinics which may not be appropriate for POCT implementation for public health access. MapMagic 13 data is not made available as digital files, so these locations were manually digitized from screen views of their maps. To do this, latitude and longitude coordinates were recorded to six decimal degrees and loaded into ArcGIS as points.

To eliminate edge effects, or the fact that people may travel to adjacent health facilities in neighboring provinces, health resource facilities were also digitized for the western and southern bordering provinces of Nong Khai, Udon Thani, Kalasin, and Mukdahan. This study assumes that people do not travel to out-of-country resources, so it was not necessary to include data across the northern and eastern borders in Laos.

Figure 5 shows the locations of health resource facilities that could serve as location for diagnostic technology, including health resource facilities in the surrounding provinces. Figure 6 also shows the location of Srinagarind Hospital in comparison to diagnostic resources surveyed currently available. Provincial totals of health facilities are summarized in Table 5. The majority of hospitals and health promoting hospitals fell within Sakhon Nakhon which correlates well with the region's larger size and population.

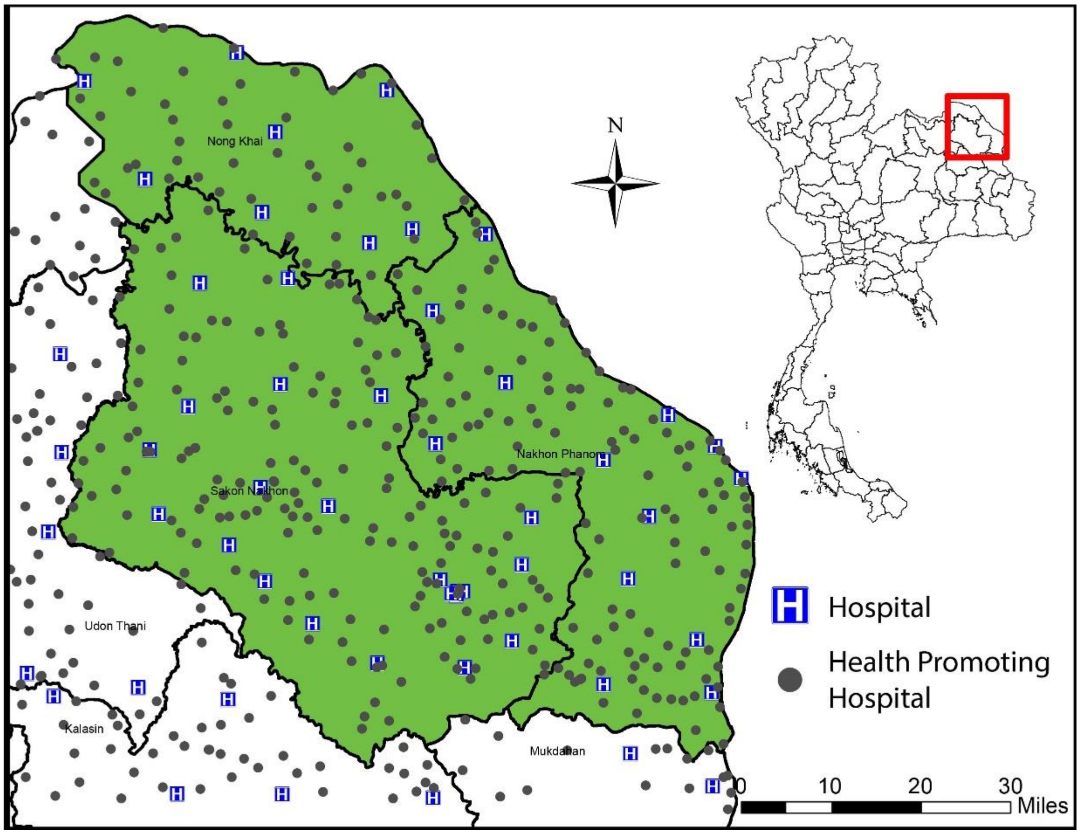

Figure 5 Hospitals and health promoting hospitals

Table 5 Health resource facilities within each province in study area

Province	**Bueng Kan**	**Sakhon Nakhon**	**Nakhon Phanom**
Hospitals	8	23	13
Health Promoting Hospitals	51	171	125
Total Health Resource Facilities	59	194	138

3.2.3 Diagnostic Technology Locations

Data on the location of point-of-care technology within the Isaan region was collected by Kost et al. (2010) in 2009 and 2010, who surveyed health facilities within the area. These locations may not represent current POCT status within the provinces; however the locations can be used to demonstrate the effects for the implementation strategies recommended in that study.

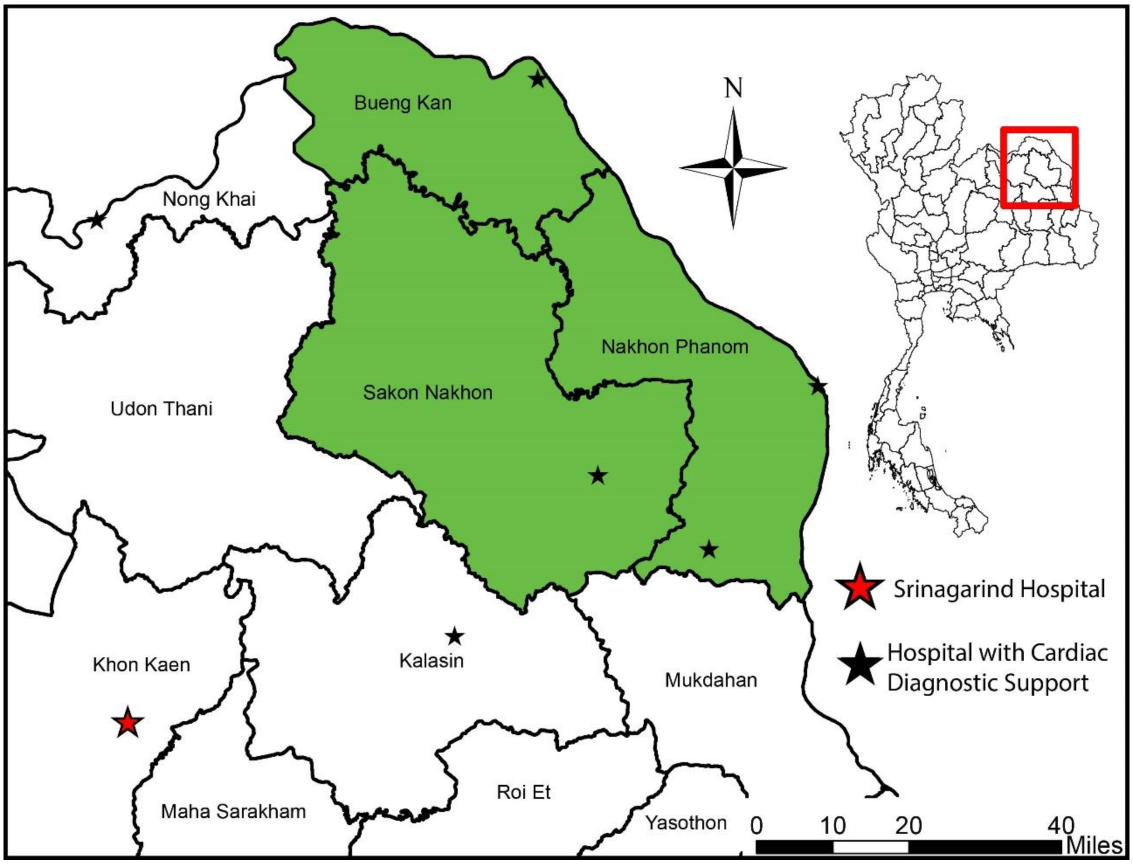

Figure 6 Current cardiac diagnostic support in the study area

3.2.4 Roads

Road data were obtained from OSM. In the OSM data, there are over 26 different categories of roads. Many of these roads are very specialized, such as link roads which are smaller roads which connect lanes of highway to other highways or adjacent roads. Since this study is limited to travel by car over larger distances, it only includes the road types that allow that form of travel. Table 5 lists the road types used in this study area and their descriptions according to OSM. Roads were obtained for the main area as well as for the provinces of Nong Khai, Udon Thani, Kalasin, Mukdahan, and Khon Kaen.

The road network for the study area is illustrated in Figure 7. Major roads are highlighted to indicate faster routes. To connect the health resource facilities to the road network 2,331 roads were added accounting for 738.3 miles of new roads. The longest road added was 6.3 miles, and an average of 0.32 miles per segment.

Table 6 OpenStreetMap road descriptions
(Descriptions modified from OpenStreetMap road metadata)

Highway Type	**OpenStreetMap Description**
Motorway	A restricted access major divided highway, normally with two or more running lanes plus emergency hard shoulder. Equivalent to the Freeway, Autobahn, etc.
Trunk	The most important roads in a country's system that aren't motorways.
Primary	The next most important roads in a country's system. (Often link larger towns.)
Secondary	The next most important roads in a country's system. (Often link smaller towns and villages.)
Tertiary	The next most important roads in a country's system.
Unclassified	The least most important through roads in a country's system - i.e. minor roads of a lower classification than tertiary, but which serve a purpose other than access to properties.
Residential	Roads which are primarily lined with and serve as an access to housing.
Service	For access roads to, or within an industrial estate, camp site, business park, car park etc.
Living Street	Residential streets where pedestrians have legal priority over cars, speeds are kept very low and children are allowed to play on the street.
Road	A road where the mapper is unable to ascertain the classification from the information available.
Link Roads	The link roads allow movement between roads.

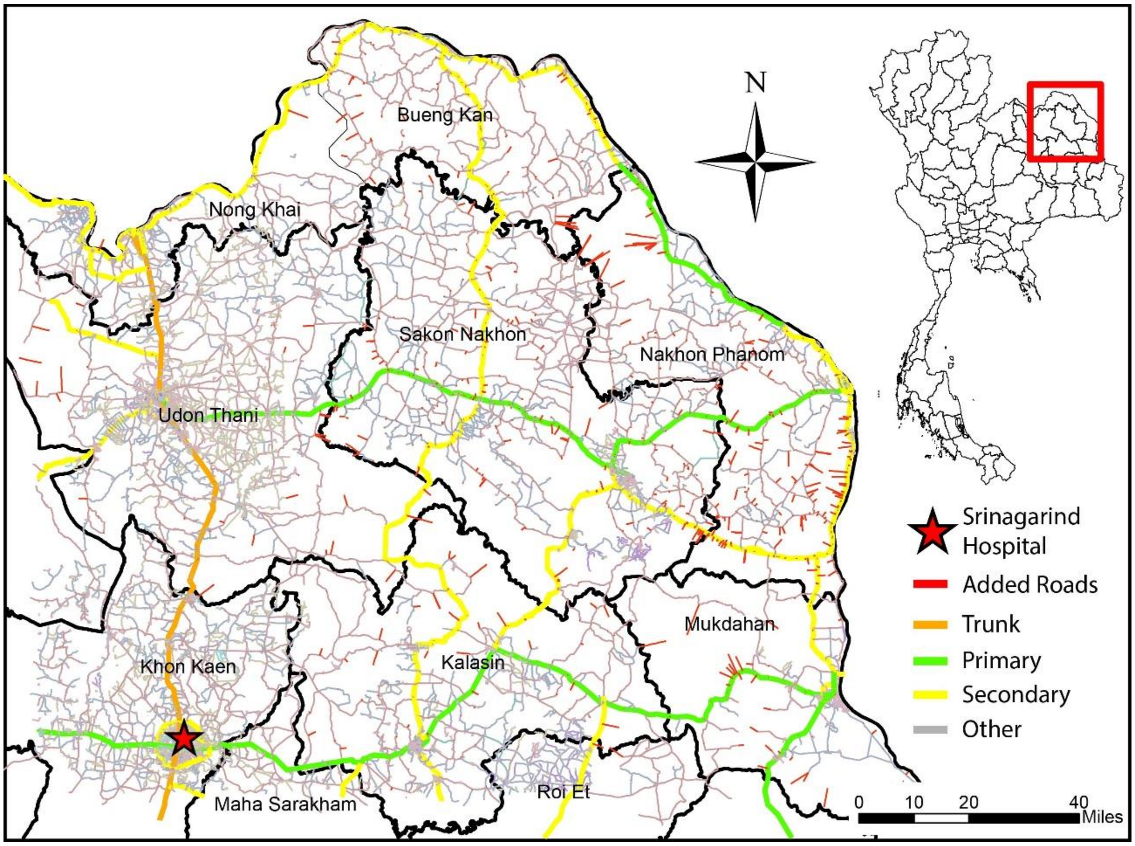

Figure 7 Added roads

3.2.5 Locations of missing data

One area in particular had a suspicious lack of roads or populated places in the OSM data. Figure 8 shows the road network in this area. This omission will impact the travel time estimates. However, for the purposes of this demonstration, it was concluded that the richness of the dataset elsewhere in the region is sufficient.

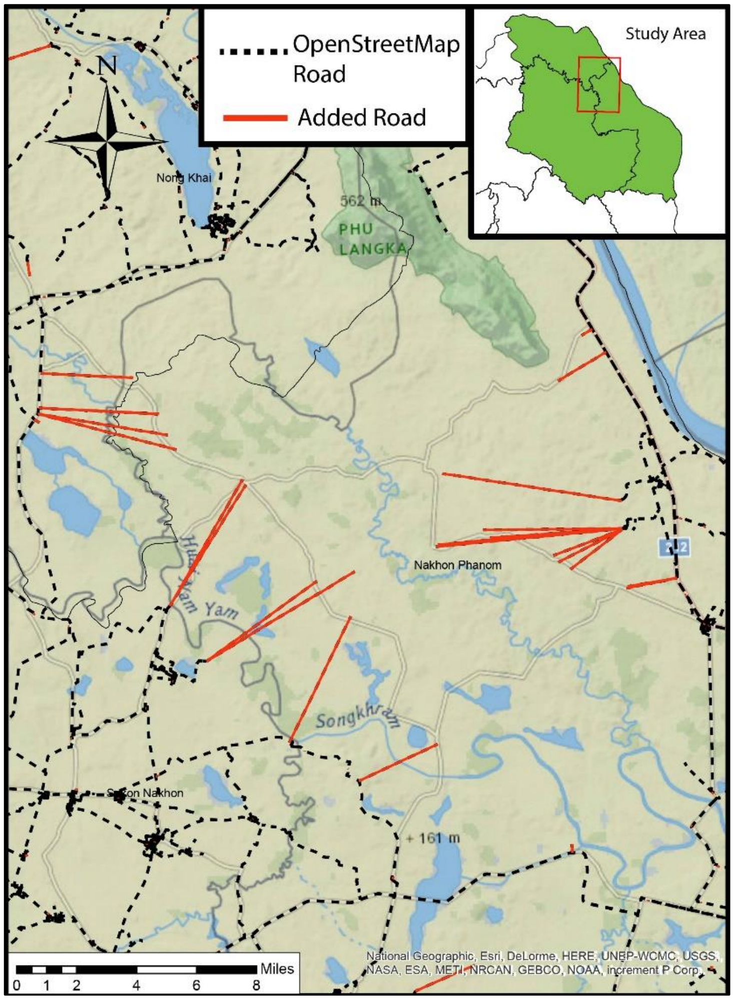

Figure 8 Missing area with low OpenStreetMap data

3.3 Methodology

The following section describes the method for a) creating a network, b) performing a sensitivity analysis using different integrate tolerances and road travel speeds, c) understanding the current health access, d) understanding the health access under widespread integration policies, and e) using a location-allocation algorithm to select best implementation sites for new POCT locations under limited resource strategies.

3.3.1 Network Creation

A GIS network is an advanced connectivity model that can be used to represent and study complex scenarios such as transportation networks. Networks are comprised of: edges (lines), which represent how entities move along the environment; junctions (points), which dictate how entities travel from line to line; and turns, which are optional elements which limit the movement at junctions between edges.

This network is used to represent the means by which people will travel from their locations to diagnostic support and then care. It was necessary to ensure that the point locations for Health facilities and population centers fall on the network, otherwise travel between points could not be modeled. When these points did not fall directly on a road, it was necessary to add connector roads. Since there was no additional information available to determine where these roads actually are, these added road segments were created simply as straight lines from the points to the nearest locations along the roads.

Since the OSM dataset is not provided in a network structure, it was necessary to process the data to ensure connectivity. Road elements that do not directly connect could vastly alter results. To ensure that these connections are correct, ArcGIS provides an Integrate tool, which snaps elements together with a given distance tolerance. The problem with this is choosing the correct tolerance and understanding the effect of that tolerance on the solutions generated. An analysis was performed to understand the effect of this tolerance on the network and is described in Section 3.3.2.2.

Figure 9 illustrates the steps to produce the network. First, connecter roads were added using the lines from the health resource facilities and populated places to the nearest point along the OSM roads. Next, using the ArcGIS integrate tool, nearby lines were snapped together using a tolerance distance of one-, five-, and ten-meters.

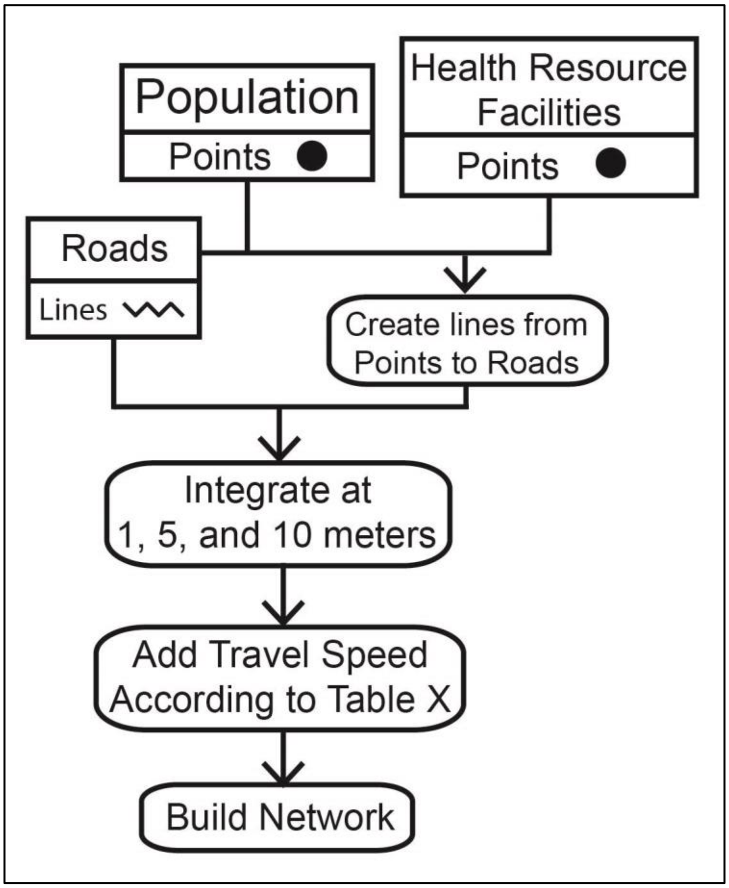

Figure 9 Methods for creating network

No turns were modeled along this network, meaning no cost was added to the routes generated from moving to one element to another and that it is possible to turn in any direction at any intersection. Additionally, interaction between elements could occur at any vertex, or wherever two elements touched.

3.3.1.1 Isolated aggregated population points

Five aggregated population points were on locations in the network that were isolated from the rest. Figure 10 displays the location of two of the places illustrating their isolation from the road network. Only one aggregated population point was on a portion of a road network with a health resource facility, however that health resource facility did not have a means to connect to Srinagarind Hospital. This was discovered late in the project and deemed a small portion of the total populated places, thus all five were removed from the analysis.

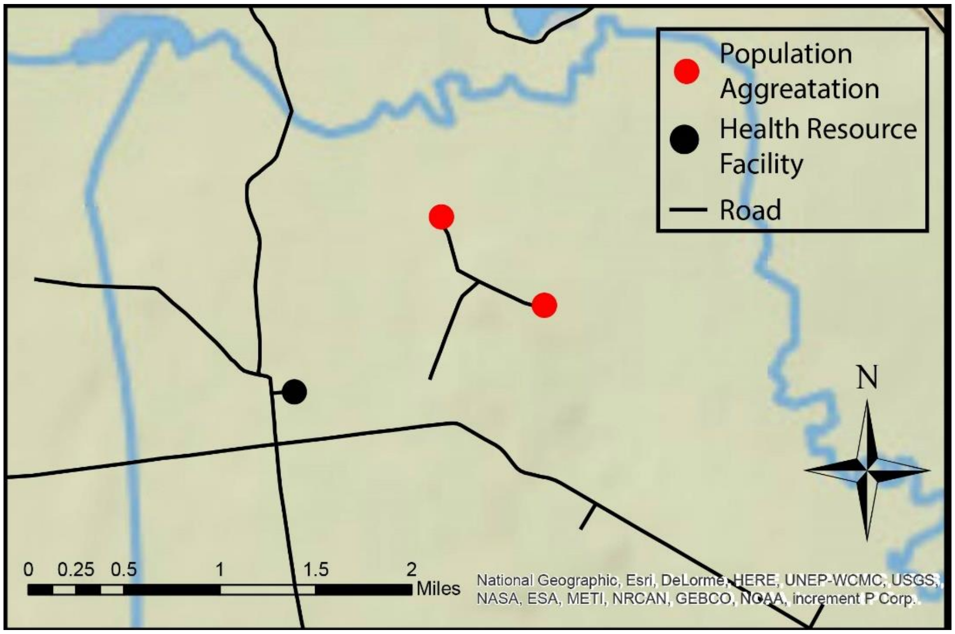

Figure 10 Populated places on isolated road network

3.3.2 Sensitivity analyses of travel speeds and integrate tolerance

Two sensitivity analyses were performed to understand the effect of travel speed in miles per hour (MPH) and integrate tolerance on health access. An analysis independently altering travel speeds (Table 7) and integrate tolerances (one, five, and ten meters) was used to understand their effect on the models calculation of health access. The sensitivity analysis used all health resource facilities (both hospitals and health promoting hospitals) to calculate health access.

Table 7 Road travel speed classification

Road Type	Estimated Guess (MPH)	Faster Highways (MPH)	Slower Highways (MPH)	Faster Streets (MPH)	Fast Highways, Fast Streets (MPH)
Trunk	65	80	55	65	75
Primary	55	70	50	55	75
Secondary	45	60	45	45	75
Tertiary	30	55	40	45	75
Unclassified	25	25	25	45	45
Residential	25	25	25	45	45
Service	15	15	15	45	45
Roads	35	35	35	45	45
Added	35	35	35	45	45
Living Street	25	25	25	45	45

3.3.2.1 Effect of travel speed

The results of the travel speed sensitivity analysis are summarized in Table 8. Mean and median travel time and distance are shown in the table. Also shown are the standard deviation (SD), minimum (Min), and maximum (Max) travel time and distances.

The estimated guess used in this analysis resulted in an average travel time to care of 160 minutes. Increasing highway speeds resulted in decrease in travel time by almost 25 percent. Decreasing highway speeds resulted in no change. Increasing street speeds resulted in a decrease in travel time by 13.2 percent. Increasing both street and highway speeds resulted in decrease of 36.3 percent, a difference of 62.2 minutes. Travel distance on the other hand was minimally altered, with a maximum average change of 2.3 percent.

Table 8 Results for the travel speed analysis

		Estimated Guess	Faster Highways	Slower Highways	Faster Streets	Fast Highways and Streets
Travel Time (minutes)	Mean MPH (SD)	164.0 (38.1)	121.4 (25.8)	164.1 (35.1)	138.9 (32.3)	101.9 (20.7)
	Median MPH (Max/Min)	170.1 (230.5/ 70.1)	124.5 (169.2/ 57.0)	167.9 (227.6/ 75.9)	142.1 (201.4/ 60.7)	103 (141.9/ 50.8)
	Mean Change Compared to Educated Guess	N/A	26.0%	0.0%	15.3%	37.9%
Travel Distance (miles)	Mean MPH (SD)	176.8 (30.9)	174.4 (29.1)	172.7 (29.2)	172.9 (29.0)	172.9 (27.6)
	Median MPH (Max/Min)	179.3 (249.9/ 107.7)	176.3 (244.7/ 106.3)	172.9 (243.7/ 107.9)	172.4 (244.0/ 106.1)	173.4 (233.3/ 105.8)
	Mean Change Compared to Educated Guess	N/A	1.3%	2.3%	2.2%	2.2%

3.3.2.2 Effect of integrate tolerance

The results of the integrate tolerance sensitivity analysis is summarized in Table 9. The differences between integrate tolerance thresholds amounted to about one minute and one mile difference between the average travel time and travel distance respectively. The results indicate that tolerance thresholds do not have a large effect on the analyses, thus a ten meter tolerance was used.

Table 9 Results for the tolerance sensitivity analysis

Integrate Tolerance	Mean (SD) Travel Time (minutes)	Mean (SD) Travel Distance (miles)
One meter	165.1 (38.3)	177.7 (23.8)
Five meters	165.0 (38.3)	177.7 (31.6)
Ten meter	163.9 (38.3)	176.7 (31.3)

3.4 Defining and Improving Access to Cardiac Care

In this study health access is quantified by travel times and distances from a) populated places to diagnosis, b) diagnosis to care, and c) the addition of populated places to diagnosis and diagnosis to care (referred to as just travel from populated places to care).

This section describes how the project quantified the current health access, and then by using widespread and resource limited implementation strategies, improved upon this access by adding POCT at strategic locations.

3.4.1 Current Health Access

The first step in improving health access is to define the current access. This was done using the road networks, road speed, populated places, health resource facilities, and POCT defined in Section 3.2 and 3.3 to evaluate current access routes and travel times from a) populated places to diagnosis and b) populated places to care were visualized and compared.

3.4.2 Widespread Strategy

Two analyses were performed to evaluate how implementing diagnostic technologies at different administrative levels will affect health access. This simulates if the health network adopted a policy that dictated certain facilities had to implement POCT.

Two scales of integration were used. The first defined health access if POCT existed in every hospital. The second analysis defined health access if POCT existed in every hospital and health promoting hospital. For each analysis, health access was quantified and compared to the current health access defined in Section *3.4.1*.

3.4.3 Resource Limited Strategy

The resource limited strategy simulates if a health network only has limited resources to improve their health networks. This analysis can be used to understand how to best utilize existing resources to improve the population's health access. It involves understanding how to rearrange existing resources for better outcomes.

Five analyses were performed which evaluated different resource limited implementation strategies:

1. Rearranged existing POCT.
2. Added 5 additional POCT while keeping the existing resources where they are.
3. Added 10 additional POCT while keeping the existing resources where they are.
4. Added 5 additional POCT while allowing the existing resources to be rearranged.
5. Added 10 additional POCT while allowing the existing resources to be rearranged.

A location-allocation analysis, using population as a weight, was used to determine the best locations for the POCT diagnostic resources in each analysis. After the health resource facilities were selected health access in each implementation strategy was compared to each other and results obtained in Section 3.4.1.

To visualize the differences between the resource limited implementation strategy results, a fixed distance euclidean Getis-Ord Gi* hot spot statistic was used. The Getis-Ord GI* statistic identifies clusters of points with value higher and lower in magnitude than you would expect by random chance. The magnitudes, in this case represented by the addition of travel time from populated places to diagnosis and the travel time from diagnosis to care, are compared at confidence levels of 90 percent (z-score of 1.65), 95 percent (z-score of 1.96), and 99 percent (z-score of 2.58) to visualize localized hot spots.

CHAPTER 4: RESULTS

This chapter discusses the results of the analysis of a) the current health access for cardiac care, b) the effects of the two widespread implementation strategies of integrating POCT diagnostic technologies, and c) the effects of resource limited implementation strategies of POCT diagnostic technologies.

4.1 Current Access to Diagnostic Technology and Care for Cardiac Events

Health access was calculated by determining the quickest route from a) populated places to the nearest health resource facility with cardiac diagnostic resources (see Figure 6) b) diagnosis to care, and c) populated places to care. The results are outlined in Table 10 and contain the mean (SD) travel time and distance.

The analysis splits the total travel time and distance into its health access components: a) populated places to diagnosis and b) diagnostic resource to care. The average overall travel time from populated places to care of 3.6 hours is mainly dominated by the travel from diagnosis to care of 2.8 hours. The minimum travel time was 1.6 hours with a maximum of 5.5 hours, a difference of 3.9 hours.

Table 10 Mean (SD) travel time for current health access

Health Access	Mean (SD) Travel Time (minutes)
Populated places to diagnosis	49.9 (25.5)
Diagnosis to care	168.6 (37.1)
Populated places to care	218.5 (39.5)

Figure 11 demonstrates the routes determined by the analysis from populated places to diagnosis. For populated places on the western edges of Bueng Kan and Sakhon Nakhon the closest diagnosis was out of the provinces. Individuals from these locations must travel west and in some cases north to reach a diagnosis.

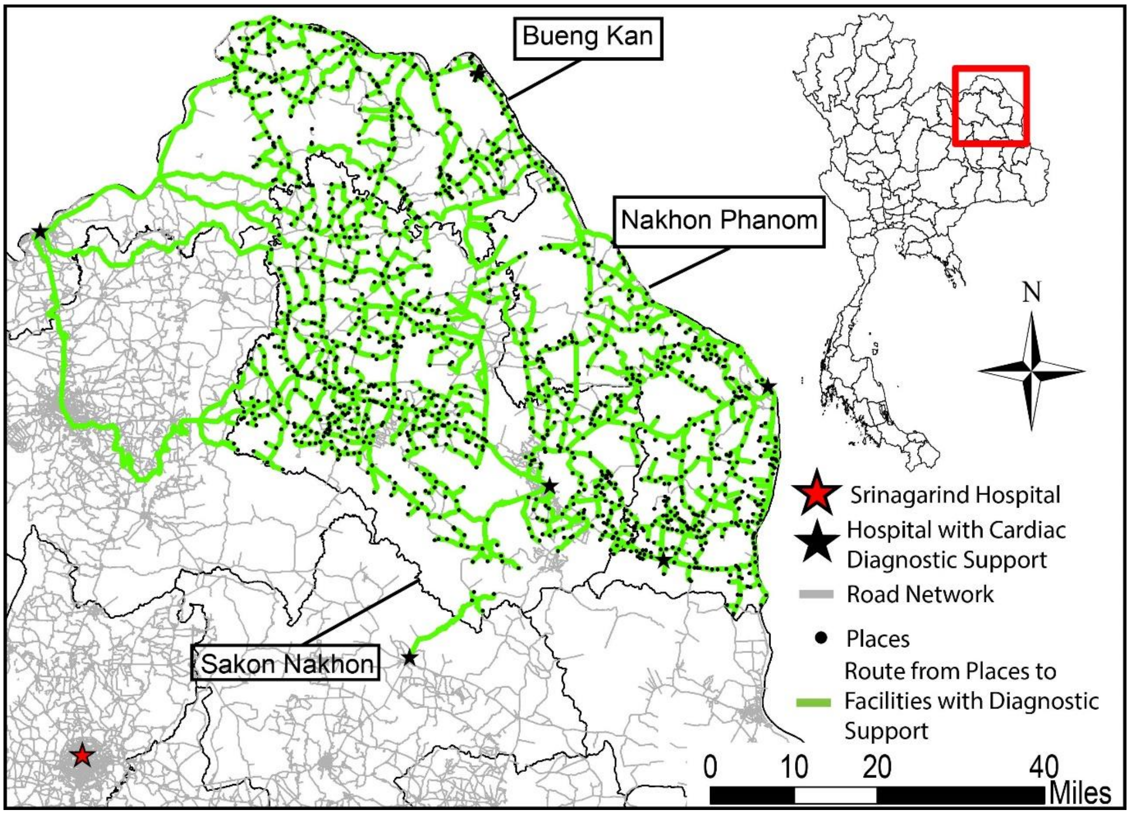

Figure 11 Selected routes for closest diagnostic facility based on travel time

Figure 12 builds on Figure 11 by adding the routes selected from diagnosis to care. Although at first it seems there is a problem with the routes selected with many heading west first and then south to Srinagarind Hospital, this reflects the major road that provides transportation east to west in the middle of Sakhon Nakhon (see Figure 7). For populated places in the western edges of Sakhon Nakhon, individuals who were identified in Figure 11 to travel west and north must now backtrack across their paths to reach care.

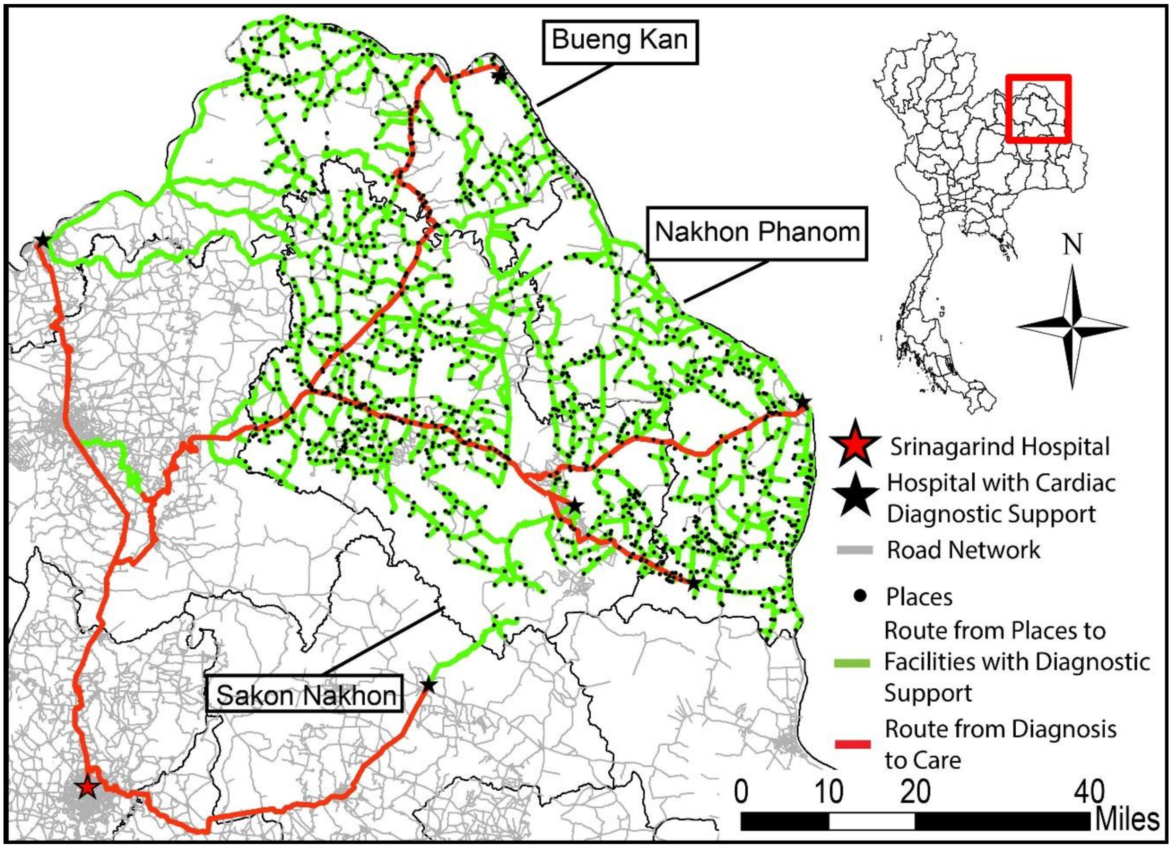

Figure 12 Selected routes from diagnostic facilities to Srinagarind hospital.

Travel time from populated places to diagnosis is indicated in Figure 13 to demonstrate the dispersion of travel times. Lower travel times occur in the eastern parts of the provinces, nearer to where the diagnostic facilities are located. Concentrations of higher travel times occurred in the north-western areas of Sakhon Nakhon and western areas of Bueng Kan where individuals must travel over 1.5 hours to reach a diagnosis.

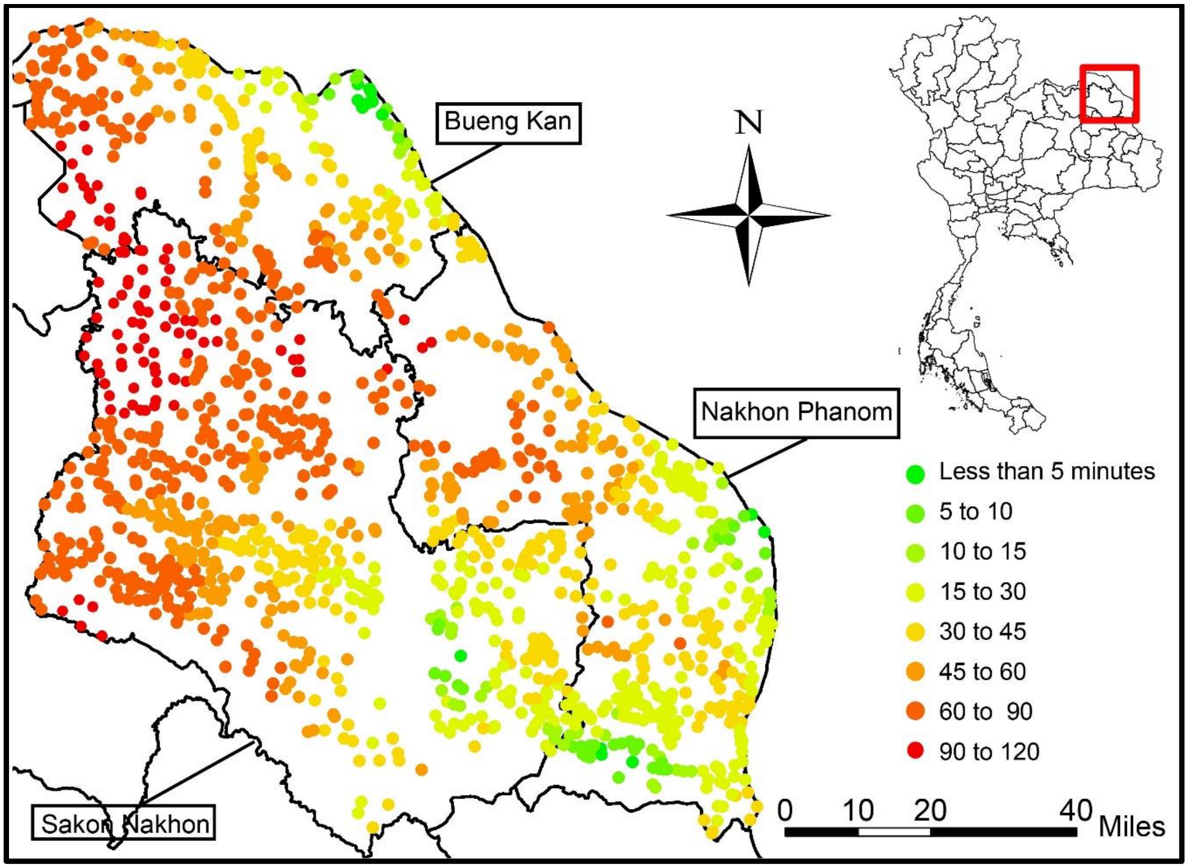

Figure 13 Populated place travel times to nearest diagnosis

Figure 14 shows the travel time from populated places to care. In the western areas of Bueng Kan there are groupings of populated places that are under two hours of care. Immediately surrounding these locations, travel time of these populated places increased to between 5 and 6 hours. These times correlate with the travel patterns identified in Figure 11 and 12, where individuals in the either travel west or directly east to reach diagnosis. Individuals who travel east must then backtrack to reach care. Although the model correctly indicated the closer facility for individuals to travel to for a diagnosis, it may be better to have a longer time to diagnosis in order to decrease overall time to care.

The longest travel times to care mostly fall in Bueng Kan. A small localized area of higher travel times can also be located in northern Sakhon Nakhon. This may be because individuals from this area must travel 1.5 to 2 hours to reach a diagnosis and then backtrack to reach care. The locations further away from Srinagarind Hospital, where you would expect longer travel times, particularly eastern Nakhon Phanom, have relatively lower travel times.

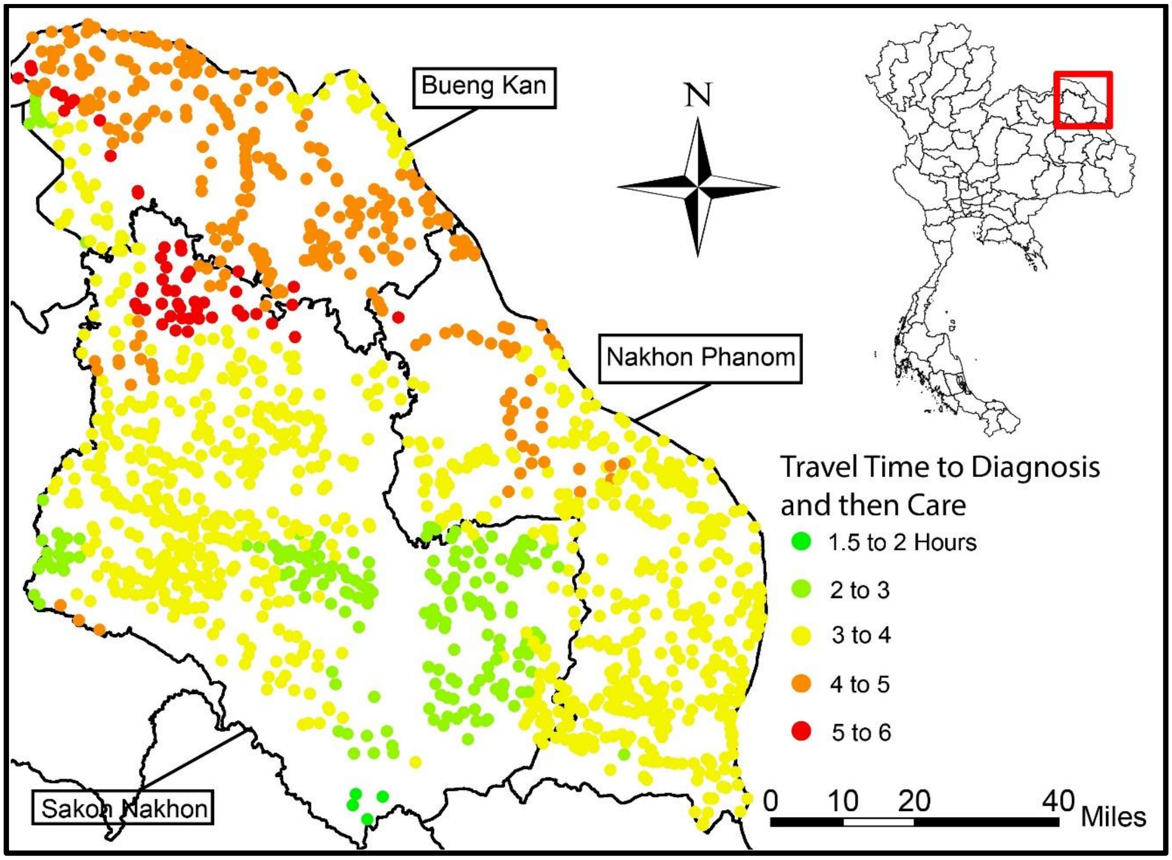

Figure 14 Populated place travel time to care

Figure 15 shows the histogram for the travel times from populated places to care and provides a means to understand the distribution of selected routes. Bins were allocated to represent 15 minute intervals. The frequency is the number of routes which travel times fall within the 15 minute bins.

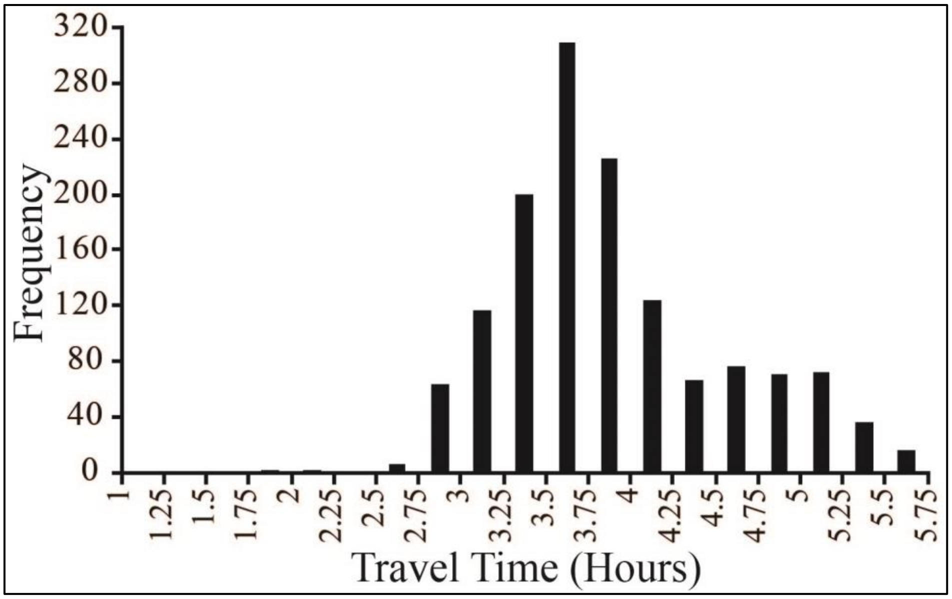

Figure 15 Travel time histogram for selected routes of current health access

4.2 Health Access to Cardiac Care with Widespread Implementation Strategy

This section identifies the travel routes determined after implementing POCT according to two widespread implementation strategies. The first strategy integrates POCT within every hospital. The second strategy integrates POCT within every health resource facility.

Mean travel time for the two strategies are shown in Table 11 compared to results from Section 4.1. Both implementation strategies offered greatly decreased travel time when compared to the current diagnostic resource access. The quickest routes were generated when POCT was implemented in every health resource facility; however it offered little advantage over integrating POCT in every hospital. The difference between average travel times from populated places to diagnosis between the two strategies was 9.3 minutes which is negligible when compared to the travel time from populated places to care. The difference between these two strategies would only result in a 2.6 percent decrease, potentially a reason to only implement POCT within hospitals instead of every health resource facility.

Table 11 Mean travel time comparison between different policy implementation strategies

Health Access	Current Access	All Hospitals	All Health Resource Facilities
Average Travel Time from Pop to Diagnosis (minutes)	49.9 (25.5)	13.9 (7.4)	4.6 (3.5)
Percent Decrease Over Current Access	N/A	72.1%	90.8%
Average Travel Time from Diagnosis to Care (minutes)	168.6 (37.1)	155.9 (37.9)	159.4 (37.9)
Percent Decrease over Current Access	N/A	7.5%	5.5%
Total Travel Time (minutes)	218.5 (39.5)	169.8 (39.9)	164 (38.0)
Mean Travel Time Percent Decrease Over Current Access	N/A	22.3%	24.9%

Figure 16 displays the results for the two strategies. In both cases analyses created a pattern of health access that starts in western Sakhon Nakhon with travel times spreading smoothly outward with increasing magnitude. This reflects the fact that populated places further away from their eventual destination of Srinagarind Hospital must to travel longer to reach the hospital. This represents a much smoother distribution when compared to the current health access (see Figure 14), where high travel times exist in small pockets or greatly increase over short distances. The two strategies generate visually the same results which indicate little differences in outcomes for individuals.

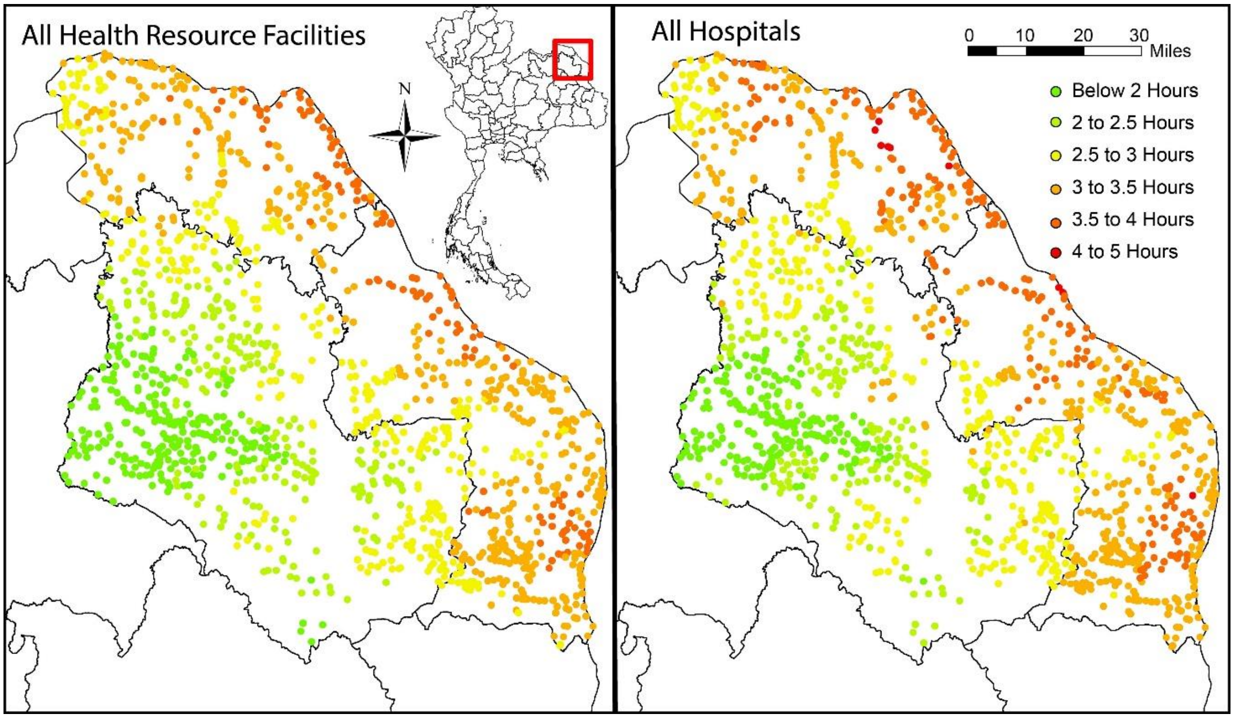

Figure 16 Comparison of population health access between different policy implementation strategies

Figure 17 shows the travel time to care distributions for the two widespread analyses compared to results from Section 4.1 in a histogram. In both cases we see the improvements in distributions. Additionally, for the two widespread strategies we can see a peak at the two hour mark, which is more pronounced in the bottom frame. This may be due to the fact that since a diagnosis can occur relatively quickly, most of the travel time being shown is a result from the distance traveled to reach Srinagarind Hospital.

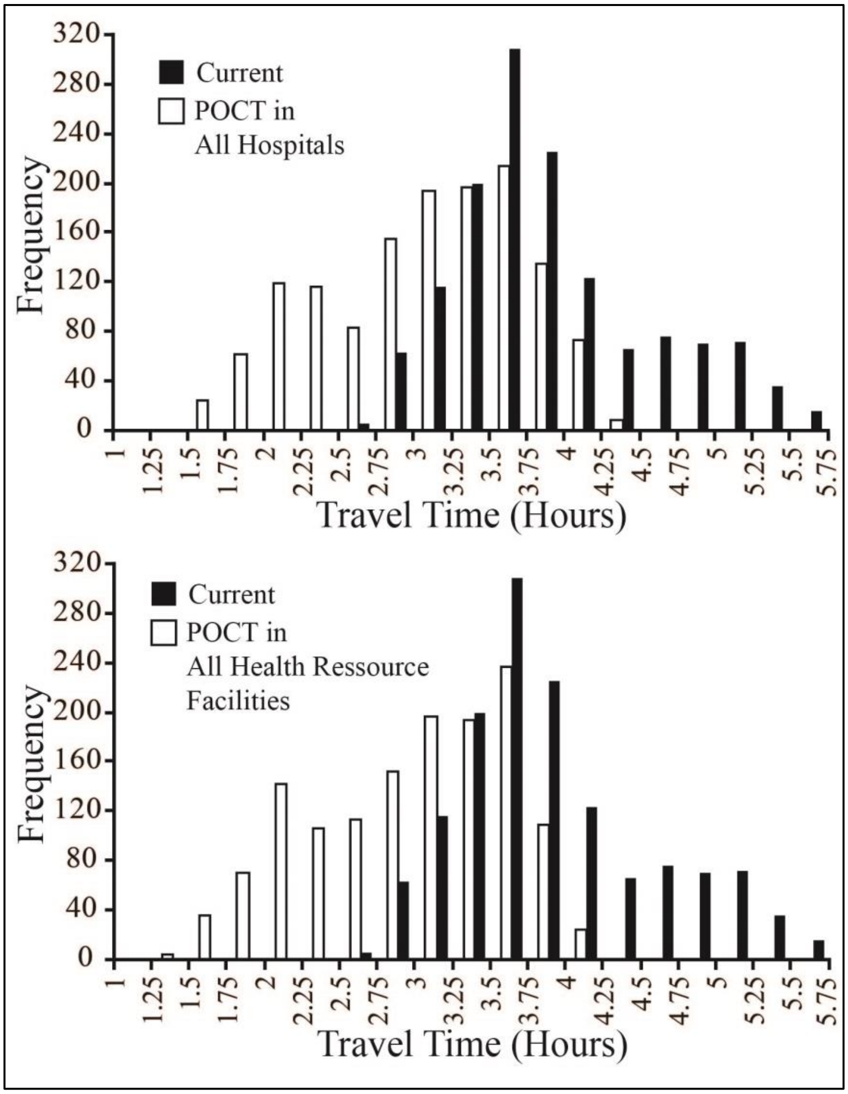

Figure 17 Histogram comparison between different health access policy implementation strategies

4.3 Optimizing Health Access to Cardiac Care

This section describes the results from the five resource limited implementation strategies which alter the amount of additional POCT tests and whether the existing resources are rearranged. Table 12 details the results of the limited-resource evaluations. When compared to current access all strategies indicate improvement compared to current access. Each strategy offers a steady decrease in travel time the more POCT were available to be integrated into the health network.

Table 12 Travel time comparison between different low-resource implementation strategies. Numbers in parentheses show standard deviation.

Health Access	**Current**	**Rearrange**	**Current Position with 5 More**	**Current Position with 10 More**	**Rearrange with 5 More**	**Rearrange with 10 More**
Average Travel from Population to Diagnosis	49.9 (25.5)	30.6 (15.3)	26.8 (13.1)	21.8 (11.3)	23.3 (12.0)	19.6 (10.6)
Decrease compared to Current	N/A	38.7%	46.3%	56.3%	53.3%	60.7%
Average Travel from Diagnosis to Care	168.6 (37.1)	150.4 (41.4)	151.4 (39.5)	151.9 (39.9)	149.6 (37.8)	153.3 (38.1)
Decrease compared to Current	N/A	10.8%	10.2%	9.9%	11.3%	9.1%
Average Travel Time from population to care	218.5 (39.5)	181 (46.1)	178.2 (42.7)	173.7 (41.9)	172.8 (40.6)	172.9 (39.8)
Decrease compared to Current	N/A	16.7%	18.4%	20.5%	20.9%	20.9%

The first analysis, rearranges existing POCT resources to better support the population in the study area, and resulted in a decrease of 16.7 percent when compared to current health access. The second and third analysis involves keeping the current POCT where they are and adding an additional five and ten POCT tests strategically to the health network. These analyses decreased travel time from populated places to care by 16.7 percent and 18.4 percent respectively. This puts into perspective that the effect of adding five additional tests in the second strategy resulted in only a decrease of 1.7 percent, which may not offer enough of a benefit when compared to the first strategy.

In the last two analyses, where existing resources were rearranged along with five and ten additional POCT, the overall effect on health access remains the same. When comparing these two strategies the difference between time to diagnosis decreased by 3.7 minutes. However this decrease was negated by the difference in travel from diagnosis to care, where having more tests in the health network actually increased travel time. Thus adding the five extra tests does not warrant the costs of adopting them, since overall it does not add any benefit.

Figure 18 illustrates the travel time from population places to care comparisons from the five analyses. Much like the results from the widespread analyses, faster travel times start lowest in the western part of Sakhon Nakhon and increase in magnitude as they spread out. This figure also demonstrates how it is difficult to visually compare the results of the strategies.

To better compare the strategies, a hot spot analysis using the Getis-Ord G* statistic was implemented using the travel times from population places to care. These magnitudes were compared at confidence levels of 90 percent (z-score of 1.65), 95 percent (z-score of 1.96), and 99 percent (z-score of 2.58) to visualize localized hot and cold spots. The results of the hot spot analysis are shown in Figure 19. Hot spots become smaller as more POCT were implemented indicating the efficiency of the transportation from diagnosis and care.

Figure 20 shows the travel time comparisons to current health access for corresponding analyses. Histograms confirm that all strategies offer a benefit over the current implementation strategy. As with the widespread implementation strategy peaks occur near the two hour mark in all except where existing resources were rearranged and ten additional tests were integrated.

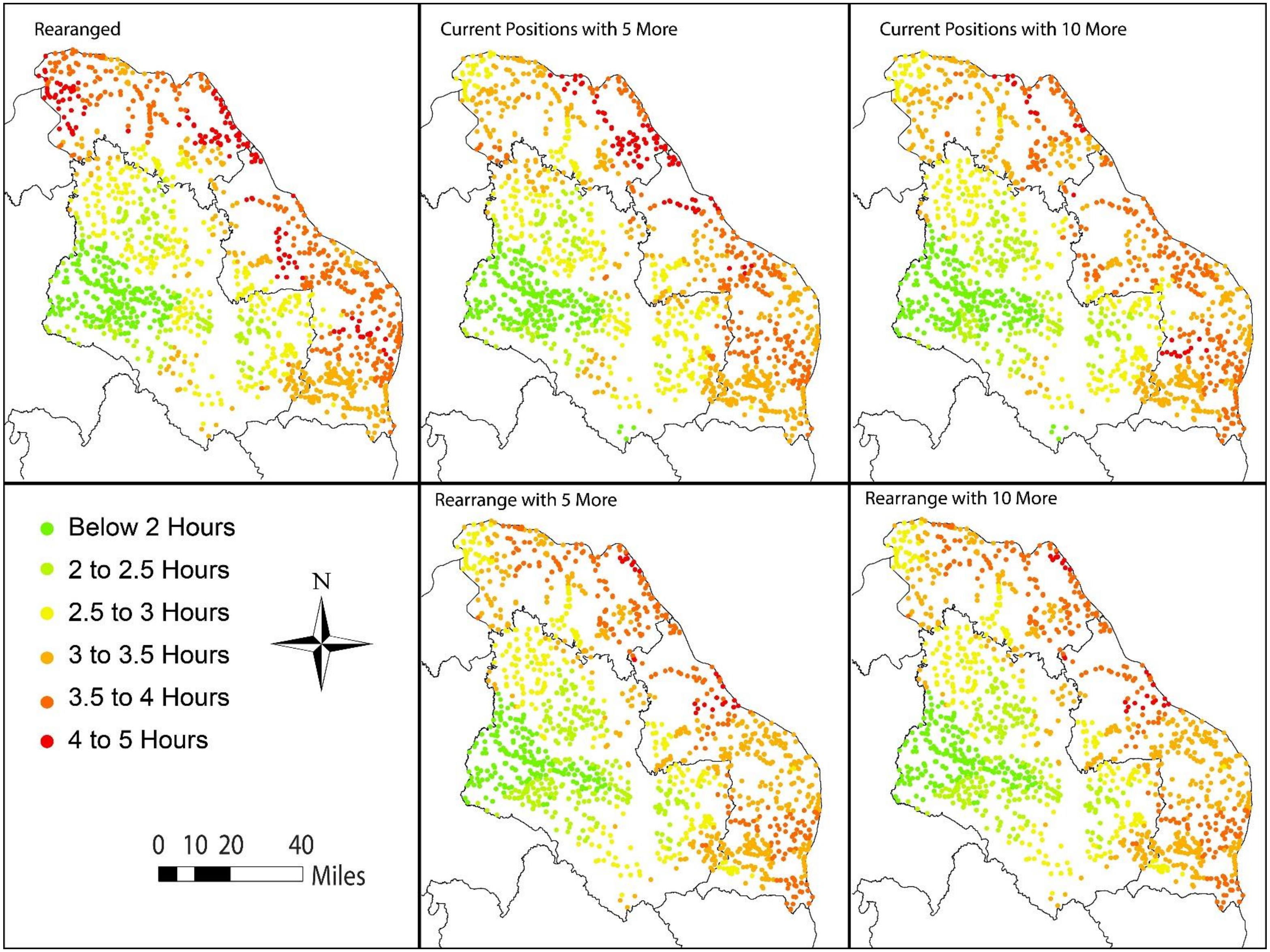

Figure 18 Travel time visual comparison between different low-resource implementation strategies

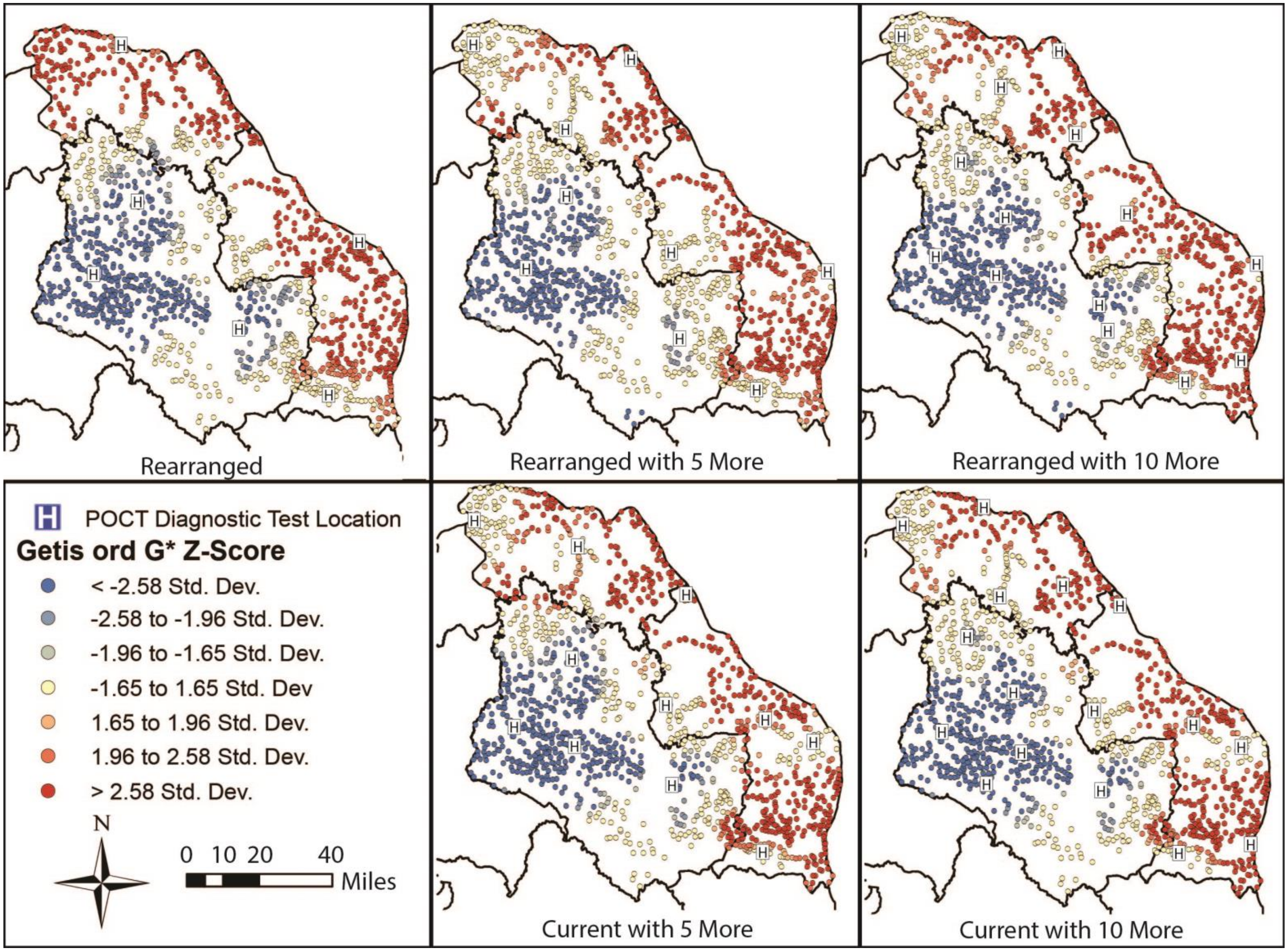

Figure 19 Travel time hot spot analysis for visual comparison between different low-resource implementation strategies

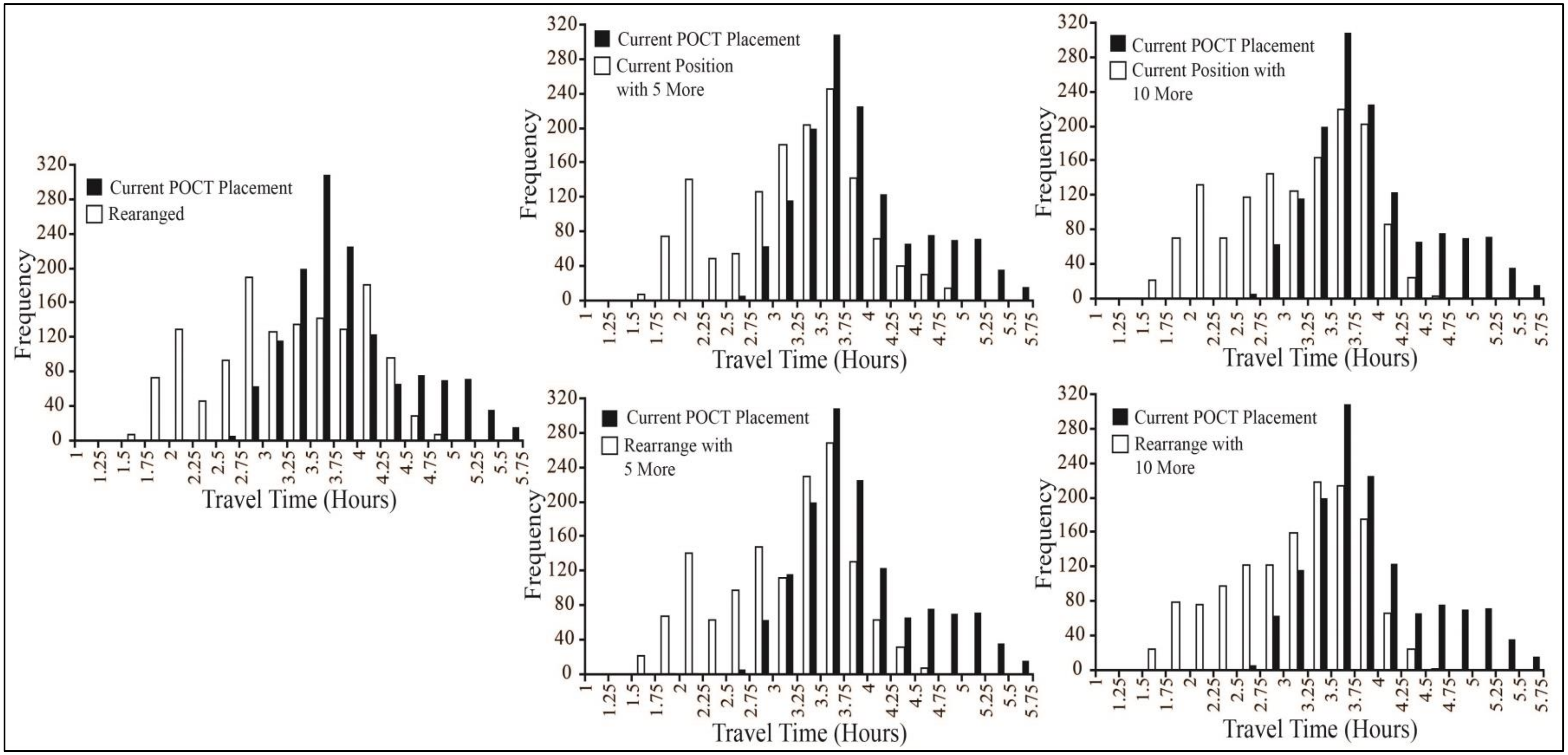

Figure 20 Histogram comparison between different low-resource implementation strategies

CHAPTER 5: DISCUSSION

The following chapter discusses the data used, critically evaluates the health access model, and discusses how the model could enable public health decisions.

5.1 Data Sources

One of the goals of this project was to provide useable outcomes using data sets that were readily available. This section discusses issues encountered with the data, their effect on the analysis, and other data sources which could be used for better outcomes.

5.1.1 Population

Location where individuals originate is a major input for this model. In this study populated places from OSM were used. It is apparent that this data source may not be appropriate for two reasons. The first is that there is no means to judge the accuracy or the completeness of this of dataset. The second reason is that the populated places may not represent the actual originating locations for individuals.

To overcome incompleteness or inaccuracy of OSM data, census totals can be used. Census aggregations may provide a better and more standardized way of obtaining origins of travel. However, the data collection timeframe and spatial aggregation may not be of appropriate scale. Census data are usually aggregated by population density. Sparsely populated areas are usually aggregated to larger area then dense populations. This may result in a poor understanding of health access due to generalization of population patterns.

One way to better represent stating locations of individual in this model is to use activity space. Activity spaces are geographically defined zones centered around the home in which everyday life unfolds (Cromley and McLafferty 2012). Activity spaces emerge from the social demand from the individual's community or household. This is a complex spatial concept which may be difficult if not impossible to incorporate into model as it exists right now. However, it is clear that a single point cannot be used to accurately represent a starting location for an individual. Activity spaces offer a better understanding of where individuals will be when they need to access their health network.

5.1.2 Roads

A major aspect of this analysis is the data used in the road network, since it determines how the model calculates travel time and distance. The model demonstrated that variations in travel speeds can drastically affect health access (Table 7). The study also demonstrated that large areas of are poorly represented by OSM due to lack of data (Figure 7).

One way to alleviate this problem is to adopt either nationally recognized data sets from the government, such as Topologically Integrated Geographic Encoding and Referencing (TIGER) roads for the United States, or commercial datasets, such as Tom Tom® and HERE®. These datasets may provide a better understanding of the road networks without gaps in data. The downside is that robust public data sets may not exist in certain countries. Additionally, commercial data sets may not be available in developing countries.

5.2 Critically Evaluating the Model

This model assumes that an individual chooses to take the quickest path to their nearest diagnostic resource and care. There are several different ways in which an individual may realistically divert from this assumption. First, a patient who self-identifies as critically ill may decide to travel in a more direct path knowing their ending destination is will be Srinagarind Hospital. Second, a patient may not have the knowledge of or does not trust certain roads or health resource facilities and thus alters their path, from a more optimal one.

These diversions from the modeled paths represent the concept of SWN, where individual paths through the network directly reflect on the cultural or social pressures that exist. A way to accurately include this into the model is to survey population or health professionals to better understand their attitudes towards their health network. This can help better understand how the population makes decisions on how they utilize their health networks.

Another limitation of this model is that the quickest path does not necessarily indicate the most efficient path to the end goal: care. This is due to the fact that the model only optimized the time to diagnosis. As identified Section 4.1, traveling to the closest facility with appropriate diagnosis may not be the most effective overall care path. Another way to preposition supplies is to optimize travel from populated places to not only a quick diagnosis but also ensuring access to care is optimized as well.

This model was created to understand a SWN in a rural low-resource location where limitations in technologies are well known. It will be interesting to see how the model behaves in more developed countries like the USA or Europe. In these locations, health access may already be optimized, in which case this model may only suggest subtle improvements or that no improvements are needed.

5.3 How this model fits into future public health decision

Health costs have consistently risen over the last few years which partially can be associated with technology development. Additionally, integration of new technology is often slow, difficult, and expensive. One of the reasons is that health networks may not have the means to understand the benefits of adopting technologies or relate those benefits to the costs of adoption (Price and John 2012).

The hope for this model is that it will fit into future decision making for all health networks by evaluating care paths in spatial framework. A spatial care path™, first defined by investigators Dr. Gerald Kost and William Ferguson as the most efficient route available to individual patients within health networks, uses geospatial information to improve decision-making and reduce costs (Kost, Ferguson, and Kost forthcoming). The expectation for the model used in this study is for it to evolve to be able to understand and implement the spatial care path™ concept within health networks.

The model, in its current condition, is not ready to be used to make decisions. Although it can be a useful tool to understand the general spatial benefit and umbrella strategies of implementing POCT, the processes modeled, data used, and the fact that it has not been validated means it is not sophisticated enough to be used in the real world.

CHAPTER 6: CONCLUSIONS

George E.P. Box wrote that “all models are wrong; the practical question is how wrong do they have to be to not be useful” (Box and Draper 1987, 74). This is relevant because spatial models can be defined as a “simplified representation of a system under study, which can be used to explore, to understand better or to predict the behavior of the system it represents” (O’Sullivan and Perry 2013, 3). Because spatial models are simplified representation of reality they involve making assumptions which inherently bias the model. This bias must be understood as to how it alters the conclusions we can reliably draw to make decisions in reality.

This model was created to understand the role of diagnostic resources within a health network. It did this by first performing a sensitivity analysis which allowed us to put into perspective how the model parameters could mislead the analysis. The second step was to understand how it calculates current health access. The third step is modelling alternative scenarios which can be compared to the current health access, helping make decisions on the best implementation strategies. To take these decisions into the real world we must understand how these benefits relate to the costs associated with the technology integration and how the modeled benefits deviate from reality.

While this project has answered many questions on how the model behaves using available data, it has raised many questions as well. How do we account for the incomplete OSM data? How does data vary from country to country? How do we better represent the starting locations for individual within health networks? How does this model change when evaluating urban environments or in developed countries? These questions will be answered as the model grows and matures. The final challenge will be to validate the model to prove that a structured spatial analysis of existing SWN will facilitate decisions improving health networks.

Despite its preliminary nature, this project has produced two significant results. The first is that this project has helped demonstrate how adopting POCT into health networks can streamline decision making at the point of need. The second is that this model has shown promise in being able to quantify the effects of implementation strategies by relating the benefits of adopting POCT to the costs of integrating them. The hope for this spatial model is that it can be used to make effective and efficient decisions that will improve individual’s health access within health networks.

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