Measuring Emergency Care Network Population Coverage with Location-Allocation Models and Geographic Information Systems

by

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Abstract

The objective of this thesis is to measure how the Nova Scotia Emergency Care Network, consisting of Emergency Departments (EDs) and Collaborative Emergency Centres (CECs), covers the population, and provide a tool to evaluate changes to the system. This study uses a Geographic Information System (GIS) and location-allocation models including the P-median problem, p-centre problem, location set covering problem (LSCP), and the maximal covering location problem (MCLP). Distance is measured in kilometres following the road network, and the population is represented as aggregate points corresponding to Statistics Canada Dissemination Areas. We analyze the existing network by computing the population-weighted travel distance of the population to each ED, the maximum distance any person must travel, and the number of people within a specified distance from an ED. We also consider several proposed changes to the network and compute the degree of improvement expected using these metrics.

List of Abbreviations Used

Term	Definition
ACSCs	Ambulatory Care Sensitive Conditions
ArcGIS	GIS produced by Esri. Includes ArcMap and ArcCatalog
CHF	Congestive heart failure
CMCLP	Capacitated Maximal Covering Location Model
COPD	Chronic obstructive pulmonary disease
CT	Computed Tomography
CTAS	Canadian Triage and Acuity Scale
DA	Dissemination Area
DA point	Point representing the relocated Dissemination Area centroid
DSM	Double standard model
ED	Emergency Department
EMS	Emergency Medical Services
GIS	Geographic Information Systems
HOSC	Hierarchical objective set covering problem
ICU	Intensive Care Unit
IOM	Institute of Medicine
IWK	Izaak Walton Killam Health Centre
LOS	Length of Stay
LSC	Location Set Covering
LSCP	Location Set Covering Problem
MCLP	Maximal Covering Location Problem
MMLCP	Maximal-multiple location covering problem
mGA	Modified Genetic Algorithm
MSAP	Maximal service area problem
NB	New Brunswick
NS	Nova Scotia
OD	Origin-Destination
OR	Operating Room
OTN	Ontario Telemedicine Network
PCP	P-centre problem
PEI	Prince Edward Island
PMP	P-median problem
Pop	Population
QEII	Queen Elizabeth II Health Sciences Centre
SPF	Split Patient Flow
STEMI	ST Segment Elevation Myocardial Infarction (“heart attack”)
TEAM	Tandem Equipment Allocation Model
UTI	Urinary tract infection
VA	Department of Veterans Affairs
VPN	Virtual Private Network

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Chapter 1 Introduction

Key components of healthcare include emergency or urgent care, and primary care. Emergency care is typically delivered in Emergency Departments (EDs) or by ambulances and paramedics and primary care is typically delivered by family physicians or through collaborative health clinics. Undoubtedly ambulances and paramedics are key elements in coverage, as changes in bricks and mortar affect ambulance and paramedic coverage, and vice versa. This research focuses on the hospital-based emergency care provided by EDs. Healthcare also incorporates planning for future patient needs and developing protocols to provide service.

In Nova Scotia (NS), there is a unique model of care designed to improve access to both the local primary care clinic and ED, called a Collaborative Emergency Centre (CEC). CECs were developed as a response to the growing need of the province to reduce wait times and even intermittent unscheduled closures of EDs, increase access to primary care, and improve physician utilization [1]. These objectives were identified in "The Patient Journey Through Emergency Care in Nova Scotia" written by Dr. John Ross. Dr. Ross identified high priority concerns for Nova Scotians as waiting too long for care, and a fear of losing existing services.

This report introduced further questions:

- How well is the current healthcare system covering the province's population?
- How well are the EDs covering the province's population?
- Are there areas that are not receiving appropriate ED services?
- Are there areas where the current system could be improved?
- Where should the ED services be?
- How do CECs fit into the existing ED system without including ambulance support?

This thesis is a response to these questions surrounding emergency care network population coverage. It is intended to provide a framework for measuring the existing system in NS. It also incorporates modelling to understand and evaluate potential/proposed changes to the system. The intent is to provide information to the decision makers who are responsible for operating and planning the NS Emergency Care Network.

This chapter provides background information on EDs in NS, as well as an explanation of the CECs model of care. We also introduce the EDs in NS, their locations, types, and the differences in services they provide. We then explain the role of the NS ambulance and paramedic provider, Emergency Health Services (EHS). Finally, we introduce the objective and outline of this thesis.

1.1 Emergency Departments (EDs)

The Nova Scotia Health Authority (NSHA) mission is "to achieve health, healing and learning through working together" [2]. They achieve this by operating hospitals, health centres, and community-based programs across Nova Scotia (NS) [2].

Historically, hospitals in NS were considered Tertiary, Regional, or Community. These labels have also been applied to the corresponding EDs. Common definitions for the terms can be seen in Figure 1.1. In addition to the tertiary, regional, and community EDs, Nova Scotia has a Collaborative Emergency Centre (CEC) model.

Disease Control Priorities Project: terminology and definitions	Alternative terms commonly found in the literature
Primary-level hospital: few specialties—mainly internal medicine, obstetrics and gynecology, pediatrics, and general surgery, or just general practice; limited laboratory services available for general but not specialized pathological analysis	District hospital Rural hospital Community hospital General hospital
Secondary-level hospital: highly differentiated by function with 5 to 10 clinical specialties; size ranges from 200 to 800 beds; often referred to as a *provincial hospital*	Regional hospital Provincial hospital (or equivalent administrative area such as county) General hospital
Tertiary-level hospital: highly specialized staff and technical equipment—for example, cardiology, intensive care unit, and specialized imaging units; clinical services highly differentiated by function; could have teaching activities; size ranges from 300 to 1,500 beds	National hospital Central hospital Academic or teaching or university hospital

Source: Definitions from Mulligan and others 2003, 59.

Figure 1.1 Definitions and Terms for Different Levels of Hospital [3]

1.2 Collaborative Emergency Centres (CECs)

In September 2009, the Nova Scotia government appointed Dr. John Ross as its first provincial advisor on emergency care [4]. Dr. Ross spoke with patients, staff, and management, and compiled the results in “The Patient Journey Through Emergency Care in Nova Scotia” report [4]. Common themes included patients waiting too long for emergency care and to see their doctor, confusion about where to go with a medical problem, fear of losing existing health services, and limited understanding of the role of the ambulance provider, EHS, and their paramedic capabilities [4]. The Ross report found patients waiting six to seven weeks for daytime primary care appointments, coupled with underutilized emergency services in rural Nova Scotia.

In response to the issues identified in the Ross Report, Nova Scotia has implemented a CEC model as an innovative design to provide better access to primary care, improve physician utilization, and keep rural EDs open. A CEC is essentially three linked components: a primary healthcare team, urgent care capacity, and a protocol for emergency care in collaboration with EHS and the NSHA. There are currently eight CECs operating in Nova Scotia, with six other possible sites identified in the Ross Report. The patient flow through a CEC can be seen in Figure 1.2.

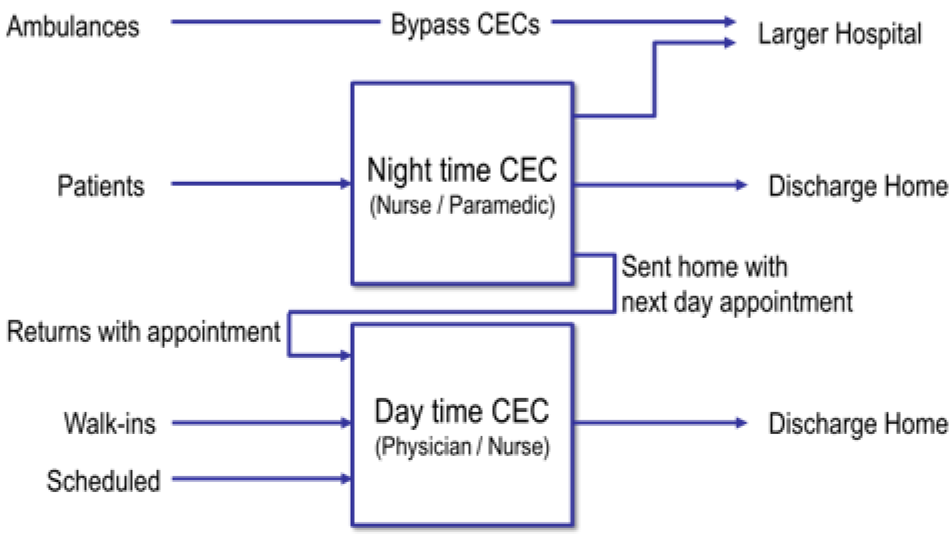

Figure 1.2 Collaborative Emergency Centre Patient Flow

Note: Night time CEC has an off-site physician who provides phone consult; Ambulances only bypass CECs at night

CEC sites are located within the ED of existing hospitals and operate differently during the day and night. During the day, there is an on-site physician and at night there is an off-site physician who provides phone consult on all patients.

At night, the CEC operates as a walk-in ED and is staffed by RNs and paramedics, with support from an EHS doctor by telephone. After seeing the RNs and/or paramedics patients are either discharged home, requested to return the next day for a follow-up appointment, or referred to a larger hospital (typically by ambulance). When paramedics respond to a 911 call at night, they bypass the CEC and transport their patient to a community, regional, or tertiary hospital instead. The daytime operation of the CEC varies somewhat from site to site, but in general, the CEC operates as a primary care clinic with scheduled appointments, and there is an ED component for walk-in patients. Patients receive care from a physician and RNs, with support from other hospital services such as Diagnostic Imaging (DI), and laboratory medicine.

The objective of a CEC is to provide better access to primary care and improve physician utilization. This will help to keep access to the emergency system open overnight.

1.3 ED Type

There are currently 37 EDs in the NSHA: one tertiary, nine regional, 19 community, and eight CECs. The Queen Elizabeth II Health Sciences Centre (QEII), located in Halifax, is the only tertiary adult ED in the province, as well as serving the maritime population for certain specialized health care needs. It is the largest teaching hospital and adult academic health sciences centre in Atlantic Canada [5]. Its services are shared between 10 buildings and two sites: the Halifax Infirmary site and the Victoria General site. The Halifax Infirmary's Charles V. Keating Emergency and Trauma Centre is the only tertiary ED in Nova Scotia. The Izaak Walton Killam (IWK) Health Centre in Halifax is a separate entity from the NSHA that provides tertiary children's emergency care to children throughout the Maritimes. The complete list of EDs and CECs, their location, and type can be seen in Table 1.1

Table 1.1 EDs in Nova Scotia

Facility	ED Type	Town	County
Aberdeen Hospital	Regional	New Glasgow	Pictou
All Saints Springhill Hospital	CEC	Springhill	Cumberland
Annapolis Community Health Centre	CEC	Annapolis Royal	Annapolis
Buchanan Memorial Community Health Centre	Community	Neil's Harbour	Victoria
Cape Breton Regional Hospital	Regional	Sydney	Cape Breton
Cobequid Community Health Centre	Community	Sackville	Halifax
Colchester East Hants Health Centre	Regional	Truro	Colchester
Cumberland Regional Health Care Centre	Regional	Upper Nappan	Cumberland
Dartmouth General Hospital	Regional	Dartmouth	Halifax
Digby General Hospital	Community	Digby	Digby
Eastern Memorial Hospital	Community	Canso	Guysborough
Eastern Shore Memorial Hospital	Community	Sheet Harbour	Halifax
Fishermen's Memorial Hospital	Community	Lunenburg	Lunenburg
Glace Bay Health Care Facility	Community	Glace Bay	Cape Breton
Guysborough Memorial Hospital	Community	Guysborough	Guysborough
Hants Community Hospital	Community	Windsor	Hants
Inverness Consolidated Memorial Hospital	Community	Inverness	Inverness
Lillian Fraser Memorial Hospital	CEC	Tatamagouche	Colchester
Musquodoboit Valley Memorial Hospital	CEC	Middle Musquodoboit	Halifax
New Waterford Consolidated Hospital	CEC	New Waterford	Cape Breton
North Cumberland Memorial Hospital	CEC	Pugwash	Cumberland
Northside General Hospital	Community	North Sydney	Cape Breton
QEII - Halifax Infirmary Site	Tertiary	Halifax	Halifax
Queens General Hospital	Community	Liverpool	Queens
Roseway Hospital	Community	Sandy Point	Shelburne
Sacred Heart Community Health Centre	Community	Cheticamp	Inverness
Soldiers' Memorial Hospital	Community	Middleton	Annapolis
South Cumberland Community Care Centre	CEC	Parrsboro	Cumberland
South Shore Regional Hospital	Regional	Bridgewater	Lunenburg
St. Anne's Community and Nursing	Community	Arichat	Richmond
St. Martha's Regional Hospital	Regional	Antigonish	Antigonish
St. Mary's Memorial Hospital	Community	Sherbrooke	Guysborough
Strait Richmond Hospital	Community	Evanston	Richmond
Twin Oaks Memorial Hospital	CEC	Musquodoboit Harbour	Halifax
Valley Regional Hospital	Regional	Kentville	Kings

Facility	ED Type	Town	County
Victoria County Memorial Hospital	Community	Baddeck	Victoria
Yarmouth Regional Hospital	Regional	Yarmouth	Yarmouth

The Emergency Care Standards [6] specific to Nova Scotia define the difference between the ED Type categories, as seen in Table 1.2.

Table 1.2 ED Historical Categorization [6]

ED Type	Physicians	Access to DI
Tertiary	(QEII/IWK) - Staffed by certified emergency physicians (RCPSC, CFPC-EM, ABEM); All physicians must meet annual requirements of their respective specialty colleges, including continuing education. In addition, they must maintain hospital and university credentialing requirements	Tertiary and Regional EDs have 24/7 timely access to DI including plain radiography, CT, and ultrasound and support from radiology within the district.
Regional	Certified Emergency Physicians (RCPSC, CFPC-EM, ABEM) must meet the requirements of their respective specialty colleges, including continuing education	Tertiary and Regional EDs have 24/7 timely access to DI including plain radiography, CT, and ultrasound and support from radiology within the district.
Community	All physicians must have current certification in ATLS and ACLS and Advanced Airway Management training, and PALS or provincially approved equivalents.	
CEC	All physicians must have current certification in ACLS and PALS or provincially approved equivalent.	

It can be seen from the table that the EDs and CECs have varying levels of physician specialization and certification, as well as varying access to other system supports such as Diagnostic Imaging.

There are also standard space and equipment recommendations that define the difference between a Tertiary/Regional ED, a Community ED, or a CEC as seen in Figure 1.3.

Emergency Department Standard Space and Equipment Recommendations				
	SPACE	CECs	Community	Regional Tertiary
1.	Safe & secure area for mental health assessment and treatment	X	X	X
2.	Spinal immobilization	X	X	X
3.	Injured limb splints, casting	X	X	X
4.	Wound management – suturing, dressing	X	X	X
5.	Procedural sedation		X	X
	EQUIPMENT			
6.	Oral and nasal airways	X	X	X
7.	Bag-mask-ventilator	X	X	X
8.	Oxygen	X	X	X
9.	Oxygen masks and nasal cannulae	X	X	X
10.	Portable CPAP		X	X
11.	Supraglottic airway device(s)	X	X	X
12.	Endotracheal airway devices		X	X
13.	Surgical airway device(s)		X	X
14.	Chest tube tray	X	X	X
15.	Intravenous lines, peripheral	X	X	X
16.	Intraosseous needles	X	X	X
17.	Blood Pressure measuring devices	X	X	X
18.	Inflatable intravenous pressure bags		X	X
19.	IV pumps, warmers, pressure infusor		X	X
20.	Refrigerated type O blood		+/-	X
21.	Arterial line system		X	X
22.	Central line tray (RN familiar with set-up)		X	X
23.	Poisoning antidote kit		X	X
24.	Orogastric lavage tray		X	X
25.	Foley catheter tray	X	X	X
26.	Pulse oximeter	X	X	X
27.	AED	X		
28.	Cardiac monitor/defibrillator/pacer		X	X
29.	12-lead ECG	X	X	X
30.	Broselow tape for pediatrics	X	X	X
31.	Broselow-coloured bags of equipment		X	X
32.	Foreign body in the eye removal equipment	X	X	X
33.	Ophthalmoscope, ENT exam tools	X	X	X
34.	Slit lamp for ophthalmic exam	X	X	X
35.	Intraocular pressure measuring device	X	X	X
36.	CT scan			X
37.	Ultrasound - bedside		+/-	X***
38.	X-ray machine available for plain films	DHAs should have a defined strategy for access to the lab tests and diagnostic imaging to support urgent and emergent care within a clinically appropriate timeframe. The strategy could include having the test available on site, plans to have the test performed at a nearby facility or transfer of the patient.		
39.	Ultrasound – radiology department			
40.	Point of care tests			
41.	Laboratory			

	LEGEND
	X mandatory
	+/- optional
	*** requires special certification

Figure 1.3 ED Standard Space and Equipment Recommendations [6]

The ED types are used throughout this thesis for context and to reflect this historic convention but are not strictly indicative of the current capacity and capabilities of the EDs.

Nova Scotia is currently working toward a formal ED classification scheme based on personnel and services, ED equipment, Diagnostic Imaging and lab, hospital services and personnel, hospital equipment, and required transfers [7]. This categorization is a work-in-progress and therefore the research presented in this thesis is based on the historical ED types. The new nomenclature aims to provide clarity for system design purposes and will include the categories shown in Table 1.3. The new nomenclature aims to better describe the available services and capabilities of the EDs.

Table 1.3 New NS ED Categorization

ED Type	Definition
Level 1	Comprehensive Full Service
Level 2	Advanced Full Service
Level 3	Full Service
Level 4	Less than full service

1.4 Emergency Health Services (EHS)

Ambulance and paramedic care in Nova Scotia is provided by EHS. Care is provided by over 1,000 registered paramedics who operate in crews of two based throughout the province [8]. The EHS fleet consists of ground ambulances, a Life Flight helicopter, and fixed-wing aircraft. EHS is responsible for responding to 911 emergency calls, as well as urgent and non-urgent patient transfers. The EHS coverage is not explored in this research but will be explored in future research as changes to EHS coverage significantly impact the EDs and CECs and vice versa.

The ED network is highly connected to the EHS provider as changes to one component of the system impact the other. This thesis does not explore the contribution provided by the network of personnel and assets of the EHS system to the population coverage by the emergency care network; future research should build on the present model to explore this element.

1.5 Objective

The objective of this study is to measure how Nova Scotia's Emergency services (EDs / CECs) cover the population and provide a tool for the Emergency

Program of Care system planners to evaluate changes to the system. This will allow decision-makers to identify the local and system impacts of proposed changes to the system and evaluate proposed alternatives. This research project uses a geographic information system (GIS) alongside industrial engineering and operations research methods.

1.6 Outline

This thesis explores many aspects of the measurement of Emergency Care Network Population Coverage using Location-Allocation Models and GIS. Chapter 2 will explore the literature surrounding Emergency Department and emergency care network structure as well as location-allocation problems and their application to the system. Chapter 3 will introduce the data and methods used throughout this thesis including an introduction to ArcGIS, population grouping, and location-allocation models. Chapter 4 demonstrates the application and results of the location-allocation models explained in Chapter 3. Chapter 4 also involves benchmarking the Nova Scotia system to the systems of New Brunswick (NB) and Prince Edward Island (PEI). The application of location-allocation models in the form of greenfield analyses, or the optimization of a new system is explored in 4.6 . An assessment of the current CEC model as well as the evaluation of possible new CEC sites is provided in Chapter 6. Chapter 7 introduces the tool that is available to stakeholders as well as its interface and capabilities. Finally, Chapter 8 includes discussion, limitations, and opportunities for future research.

Chapter 2 Literature Review

2.1 Introduction

This chapter provides a literature review exploring various components of emergency care systems. The literature covers many aspects of these systems however this review focuses on eight themes. This literature review begins by discussing models used to determine hospital locations, network structure design, and gauging accessibility to healthcare through spatial measures. Next, measures of appropriateness of care, innovation, and ED categorization methods will be explored. Finally, a review of models to choose ambulance base locations will be described.

2.2 Hospital Location

Locating a new hospital is an important, infrequent decision for healthcare providers and this section reviews articles that address the challenges of hospital planning. The use of models for determining the location of hospitals and ambulances, along with spatial measures will be used as a basis for further research applied to the Nova Scotia EMS system.

Location-allocation models are used to guide hospital planning because they allow for analysis of the effects of opening, closing, or resizing facilities in relation to multiple objectives, as well as comparison with the current system. In [9], location refers to the decision of where to place the hospital and allocation is defined as the determination of distribution patterns. They present two location-allocation models for dealing with uncertainty in the planning of hospital networks. The first model is similar to other models in the literature and deems location a first-stage decision and uses a common assumption in which the allocation decisions are made once uncertainty is revealed. The second model regards both location and allocation as first-stage decisions and reasons that allocation decisions need to be made before uncertainty is disclosed and therefore unsatisfied demand and extra capacity should both be modelled.

Both models presented aim to help with the organization of the hospital network, patient flow within hospital services, hospital capacity, a planning horizon for scheduling decisions over time, and a trade-off between access and cost. The models also account for the two-tier structure of district and central hospitals, and multi-service hospitals providing inpatient, outpatient, and emergency services. The first model was shown to be quite restrictive as it could be driven by a single extreme scenario with low demand and was too constrictive for uncertainty planning. The second model is shown to be useful in terms of flexibility and because critical planning decisions are not as scenario dependent [9]. In healthcare, it is advantageous to make allocation decisions in the first-stage as it helps to create more stable catchment areas.

Watts et al. used location-allocation modelling to optimize the number and location of sleep laboratory facilities through cluster analysis and the geographic distribution of the patients [10]. Their objectives included minimization of travel time for the total patient population, maximization of patients within a desired travel radius, and minimization of total cost. The study suggests that location-allocation models can be used to optimally locate any medical service.

Selecting the location for healthcare facilities includes both minimizing costs and maximizing benefits and originally used small datasets with simple measurement functions. GIS methods changed this and allowed the use of larger datasets with more complicated data structures, as well as more accurate spatial measurement, analysis, and modelling. Indriasari et al. [11] performed a study using GIS methods to incorporate road accessibility conditions. Most conventional facility location models use a circular-shaped region based on a specified radius of accessibility, however when locating facilities such as fire stations and ambulance bases the service time must include road access, barriers, and road network attributes. Response time or distance travelled is a vital factor in the measurement of emergency services and emergency facility locations are typically modelled under time or distance constraints. They explore a variety of different location models including the P-median problem, and p-centre problem, as well as the location set covering problem (LSCP), the maximal covering location problem (MCLP), and the maximal service area problem (MSAP). We will briefly review these models and their applications.

The P-median problem is described as a way to locate many private and public facilities by minimizing the average distance travelled [12]. The P-median problem's objective is to minimize the total or average distance between facilities and demands that they are assigned, whereas the p-centre problem aims to minimize the furthest distance. In the case of emergency services such as ambulances or fire stations, minimizing the average distance is not appropriate, and a more effective method involves using a maximum acceptable travel distance or time. Coverage is a critical component of emergency services location, and a demand must receive service within a specified time to be considered covered.

There are two streams of covering problems in the literature. The stream where coverage is required includes the LSCP, and the other stream, where coverage is optimized includes the MCLP [12]. In the LSCP, the objective is to minimize the cost of facility location to reach a designated level of service, which is modelled to determine how many facilities are needed to obtain this specified level of service for all customers. The LSCP looks for the optimum number of facilities, in addition to meeting constraints that require each of the demands to be met by at least one facility [11]. In many real-life applications, there will not be sufficient resources or budget in to build a facility in each of the locations generated by the model and in this case the locations must be shifted to cover as many customers as possible with the designated level of service [12]. This turns the set covering problem into the MCLP. The MCLP has a predetermined number of facilities and the objective is to maximize the service for the demands within a set service distance or time.

The MCLP model is built on to develop the maximal service area problem (MSAP), which has the objective of maximizing the total service area of a fixed number of facilities [11]. The MSAP incorporates GIS to produce service areas for facilities as travel time zones. The service area is either the closest area to a facility in distance, time, or cost, or the area that can be reached from the facility in a specific distance, time, or cost. GIS is used to generate service areas as travel time zones in the facility location problem. The modification of the MCLP model to incorporate GIS to create the MSAP accounts for the real road network and accessibility to create a more accurate solution.

Indriasari et al. [11] used the genetic algorithm to solve the MSAP and compared the results to the tabu search and simulated annealing heuristics. They looked at the existing sites and then used the algorithm to create an optimal solution and compared the results. The genetic algorithm gave better solutions but the simulated annealing was slightly faster to run, while tabu search appeared to give the best solution quality and computation time. All three methods provided better coverage than the existing facilities which shows the effectiveness of using GIS and modelling techniques to develop facility networks.

In [13] the MCLP is used to model location allocation for healthcare facility planning in Malaysia. They explore the model by formulating the problem as a Capacitated Maximal Covering Location Model (CMCLP) to handle the limited capacity of each of the facilities. The paper indicates that the MCLP model is typically useful for determining the locations of ambulances, police, and fire stations because worst case performance is a critical component, however healthcare planning involves various limitations to ensure quality services are provided. The CMCLP was introduced to link the un-capacitated models, the capacitated models, and generalized assignment problems to exhibit how small and medium problems can be solved using existing methods.

In [13] a modified Genetic Algorithm (mGA) is used to solve the CMCLP for locating facilities in Malaysia and then compared their results with the results reported for a 20-node network problem in 1996 by A. Haghani. They then extended the algorithm to a 179-node real data set and compared previous location decisions with the optimal locations using CPLEX. The model was used to consider improvement to the existing coverage through upgrading existing facilities, or adding new facilities that were outside the existing coverage. New facilities were considered in areas of high population growth, or areas that currently had healthcare provided through mobile clinics. The analysis identified potential new locations and expansion of existing facilities as well as the recognition of undesirable facility locations.

Syam and Côté [14] explored a different facility location problem based on the delivery of specialized services within the Department of Veterans Affairs (VA) in the United States, with the goal of optimizing the cost of providing care, as well as access and availability. Fixed costs, treatment costs, travel costs, lodging costs, lost service costs, and overloading penalty costs were included in the model. Patients and their families are responsible for travel and lodging costs, while VA is responsible for the other costs. There is a specified service level for each level of acuity, and higher acuity patients will require longer lengths of stay (LOS) and more resources. The model is used to analyze the trade-off between a small number of centralized treatment units located in large urban areas compared to many small decentralized treatment units located in both urban and rural or low-density population areas. This allows the model to consider both VA costs as well as secondary objectives such as patient travel and lodging costs. The model also incorporates constraints that ensure that the capacity of each facility by acuity is not exceeded and that the mandated service levels are met, as well as a common resource pool at each centre. The study provides the comparison between the results with a centralized two-centre system set against a decentralized five-centre system and the findings conclude that the decentralized system is costlier but serves more patients. The model can be adjusted based on parameters that the decision makers are concerned with such as different target utilizations, service levels, overload penalty cost, and for lost admission cost.

2.3 Network Structure

This section will discuss different views of network design. The Institute of Medicine's report "Hospital-Based Emergency Care: At the Breaking Point", establishes that the goal of regionalization is to “improve patient outcomes by directing patients to facilities with optimal capabilities for any given type of illness or injury” [15]. They describe other benefits of regionalization to include reduced inventory through pooled warehouses, and improved capacity to serve the population.

Carr and Martinez [16] define regionalization is defined as a process where patients are appropriately matched to the correct resources, and define centralization as unplanned over-triage of patients to large centres. They conclude that regionalization is not centralization. Wiebe and Scott [17] explain how regionalization and categorization of care are not new to healthcare and that the origins can be linked to the triage of patients on battlefields. They explain how battlefield aid stations were bypassed to transport critically injured patients to definitive care compares to how present-day community hospitals are bypassed to transport trauma patients to a regional centre. One of the biggest concerns with the regionalization and categorization of healthcare facilities is that it means identifying facilities as “better than” or “worse than” other facilities, and every facility aspires to be “the best”.

Kahn et al. [18] explain how trauma and critical illness require around the clock extensive infrastructure and equipment, advanced imaging, and operating rooms. They recommend centralizing care for the most critical patients, as reproducing expensive infrastructure at multiple hospitals in a region is costly and inefficient. The study indicates how under a regionalized structure, critically ill patients would be transferred to high-performing centres and the sickest patients would be sent to specific centres of excellence. Triage and patient transport are important when considering the regionalization of emergency care, as it is important to determine which patients should be sent to the best facility for their care.

2.4 Spatial Measures

Spatial measures are an important indicator of how accessible healthcare is to the population. This section will review different measures of spatial accessibility and how they can be modelled. In [19] it is noted that spatial accessibility is particularly important as travel and waiting time influence how patients choose their healthcare provider. Low- and middle-income patient demand are highly sensitive to travel and wait time.

In [20] the potential spatial accessibility to primary health care is gauged using a gravity-based measure within a GIS framework by using straight-line distances between population cluster and the health facilities. The straight-line distance measure calculated the travel distance between healthcare providers and population clusters. The assumption of the gravity-based computation method is that residents from within a region may use health services other than the one nearest to their location and they associated each population cluster to the nearest two health facilities to use this method. The travel distance as well as the supply and demand of healthcare services were then used to measure both regional and national accessibility. Accessibility is the measure of choice as the goal of Bhutan's health system is to achieve 100% coverage of primary healthcare services. This type of study is proposed for long term planning and the use of "what-if" scenarios such as the implications of increasing health facilities or health providers.

A three-stage sampling design stratified by county and ethnicity was performed in [21] to determine the importance of geography and spatial behaviour in rural health care utilization. The multivariate analysis included factors such as having a driver's license, use of provided rides, and the distance for regular care, as well as age, gender, ethnicity, household income, and need. They conclude that distance to care was an important influence in the number of healthcare visits that patients had in a year as greater distance resulted in fewer regular check-ups. Distance was not significant for shaping the number of chronic and acute care visits that patients made.

The Ontario Telemedicine Network (OTN) has introduced technology as an innovative way to provide more accessible medical service to remote areas of Ontario [22]. OTN units connect patients to care providers using telemedicine equipment connected to the OTN secure virtual private network (VPN) communication system. O’Gorman and Hogenbirk used the ArcGIS Network Analyst to analyze the service area of OTN locations using travel time as a measure of potential access to care, and road distance and speed limits to estimate the travel time between communities and the nearest OTN unit in Northern Ontario. The study received a list of units from OTN which they used to match to community names on the Ontario Ministry of Natural Resources settlement layer, and used the postal codes for any communities that did not have a match. They verified the population and data, and then used the Network Analyst extension for ArcGIS to create polygons of 30-minute and 60-minute travel times from the OTN units by private vehicle as there is low access to public transportation in the rural communities. They created categories including communities within a 30-minute drive from the nearest OTN unit, communities between 30-minutes and 60-minutes from the nearest OTN unit, communities more than 60-minutes from the nearest OTN unit, and communities with limited or no road access to an OTN unit. They performed manual distance checks in 20 randomly selected communities, and then performed a statistical analysis using Pearson’s chi-squared tests to compute if there were differences in travel time among the population groups of the communities or between rural and urban communities using the Monte Carlo method. They concluded that their method can be used to estimate potential access to medical care and healthcare and can indicate areas for improvement for consideration of future OTN unit sites.

The determination of a site for a hospital to replace a hospital destroyed by flooding in the Village of Gowanda, New York that was destroyed in a flood was done using spatial analysis. Ameroso [23] used ArcGIS software determine the new site location using geographic variables. Factors such as minimizing distance to demand points, service to remote areas, employment, and existing infrastructure were included in the model, and the MCLP was used to maximize distance covered given a fixed number of locations.

The study began by performing a Suitability Analysis to ensure that the new location was outside of the floodplain, had less than a 25% slope, and met the required parcel classifications. They next created a Suitability Surface using the acceptable layers determined in the Suitability Analysis and modified the samples to use consistent sizes. The next step involved selecting parcels that were suitable based on the Suitability Analysis and Suitability Surface results. Only parcels that were completely suitable were considered, all residential land parcels were discarded, and only parcels that were at least 1 acre were considered. The next step, Network Creation, examined the existing transportation network as the new hospital must be accessible using existing infrastructure and all parcels that did not connect to the existing network were rejected. Service Areas were then created at each suitable point using ArcGIS based on how much distance was covered in 30 second increments along the transportation network. The last step, Data Analysis, examined how many parcels each potential location covered in each 30 second increment, and the percentage of residential and commercial areas that were covered by each potential site.

Coverage was an important part of the decision and the daytime and nighttime expected populations were inspected and scored to determine which potential sites would have better day or night coverage. The data was then analyzed to determine which sites were more effective at covering the highest percentage of parcels, and the highest daytime and nighttime parcels. Any facility that did not meet the average percentage of parcels covered by all potential facilities for each time break was discarded, and then the same process was repeated looking at the day and night parcels. This left the study with five potential sites which were then compared based on the land size, number of connections to the transportation network, whether they were commercial or residential areas, and whether they were privately owned or owned by the village. The final site was owned by the Village of Gowanda, was in a commercial area, was connected to the transportation network in two places, and was sufficiently large to build the new hospital on. This method results in a somewhat intuitive result as the selected site is land that already belongs to the village, and is well connected to the transportation network. It demonstrates that the stepwise methodology produced plausible results and indicates that the method could be used in other areas when analyzing current facilities or when placing new facilities.

2.5 Appropriateness

This section introduces how to measure appropriateness of care within Emergency Medical Services (EMS) system. It was revealed in [19] that patients initiated ED visits are used as substitutes for general practitioner and specialist visits. The use of emergency services as primary care for non-severely ill patients can be considered inappropriate care. This misuse of urgent care resources can place unwarranted strain on the emergency system.

A measure of appropriate healthcare use is the United States is the analysis of Ambulatory Care Sensitive Conditions (ACSCs) [24]. ACSCs are represented by short-term diabetes complications, long-term diabetes complications, uncontrolled diabetes, lower extremity amputation in individuals with diabetes, adult asthma, hypertension, dehydration, urinary tract infection (UTI), bacterial pneumonia, angina without procedure, chronic obstructive pulmonary disease (COPD), and congestive heart failure (CHF). The study modelled the twelve ACSCs in a multivariate approach to incorporate the correlation structure of the ACSCs, as some share common comorbidities or behavioural risk factors. Modelling these variables using spatial structural equation modelling showed that counties with low access to primary health care also had unhealthy lifestyles, high rates of disease prevalence, as well as a low tendency to use health care. The study showed that counties with the least access to primary healthcare had more ED visits. The identified counties with high rates of ED visits for ACSCs were also shown to not have community health centres which corresponded to higher rates of hospitalization for ACSCs. This indicates that measuring the presentation of ACSCs in the emergency demonstrate low access to primary care which leads to non-urgent patients receiving primary care in the emergency department.

2.6 Innovation

This section will discuss several innovative solutions to hospital-based emergency departments. These solutions were intended to change the way people are receiving primary and emergency care. Freestanding EDs were introduced in the 1970s to support communities that could not sustain hospital-based EDs [25]. In the US, they are a growing source for unscheduled acute care and have increased from 222 freestanding EDs in 2009, to 360 in 2015. The study performed by Schuur et al. created an inventory of freestanding EDs in the US and then took the three states with the highest number of freestanding EDs (Texas, Colorado, and Ohio), and connected data, such as demographics, insurance, and health services, using the ZIP code matching the freestanding ED's location. They compared this information with non-freestanding ED locations to identify similarities and differences. It was concluded that, in all three of the states, the freestanding EDs more favourably chose to be located within ZIP codes with higher population growth rates, higher median income, and where the population was more likely to have private insurance.

Ontario's implementation of the OTN has presented technology as solution to provide medical service to remote areas of Ontario [22]. These OTN units are typically located in healthcare centres such as hospitals, nursing stations, medical care clinics, public health units, and treatment centres, and use telemedicine equipment connected to the OTN secure VPN communication system. They identified that patients who must travel long distances to receive care attended fewer chronic disease checkups or preoperative assessments before surgery. The introduction of telecommunication technology through a secure VPN communication system enables patients to access care with reduced travel time.

Nova Scotia has developed CECs as a response to access problems within emergency and primary care services in rural areas [26]. A rapid knowledge synthesis was performed by Hayden et al. (2012) which identified that ED overuse is linked to inaccessibility to primary care; however, extending ED services does not seem to have a major impact on reducing inappropriate ED use [27]. It was recognized that collaborative primary care has demonstrated a consistent improvement in the symptoms and management of chronic disease and that multidisciplinary emergency care teams may be successful in improving access. Many rural EDs in Nova Scotia provided inconsistent access due to physician shortages and other operational issues resulting in closures [28]. According to the report “The Patient Journey through Emergency Care in Nova Scotia” when physicians were on call in rural EDs overnight they were then unavailable to work in their clinic the following day causing a reduction in access to primary care [4]. CECs are a healthcare delivery model that bring nurses, doctors, paramedics, and other healthcare providers together into a team-based approach in a common location to provide urgent and primary care [26]. Hayden et al. describe a CEC-type centre as a seamless collaborative team approach to providing both primary care and access to emergency care [27]. They were originally defined by the Nova Scotia Department of Health and Wellness as “a model that brings together rural community emergency departments and local family practices to work together to provide seamless access to primary and emergency care to the community”. A CEC formally links a primary healthcare team, the capacity to provide urgent care, and protocols for emergency care.

2.7 ED Flow

This section will review methods used for measuring the quality of patient flow and bed utilization within an ED. Cochran and Roche use queuing performance measures to determine the quality of an ED [29]. They observed that the metrics for patient waiting times and area overflow probabilities work best to ascertain success. They also postulate that beds should be 20% empty, or have an average utilization of 80%, to ensure that the wait times and overflow probabilities are reasonable and to minimize blocking between areas. They use a case study of a hospital in Phoenix to implement Split Patient Flow (SPF) which treats lower acuity patients in a different queue from the high acuity patients who are waiting for an ED bed. This allows the lower acuity patients to use a bypass lane removing them from the delay caused by waiting for an ED bed. They obtained data to determine the acuity split at the hospital which can be estimated from hospital data using national patient population standards, and to estimate the service rates. They then determined the routing matrices and patient flow probabilities to establish the potential routes that any patient could take through the ED. They next looked at quantifying the demand peaks through hourly and seasonal patient arrival patterns but conclude that the time of day arrival is a more universal measure than monthly seasonality. They followed this with calculating the patient flows to all nodes in the ED, and establishing the quality of service performance goals. They set an initial overflow probability for the Inpatient ED services and the Admit Hold area, an expected wait time of five minutes in the queue for registration, and 15 minutes for the Intake, Inpatient ED, and Admit Hold areas. They then capacitated the nodes using queuing and compared the results with the performance goals which was followed up with validation with hospital staff. They concluded that the time from when a patient enters the door to the time that they see a doctor has been reduced and provides improved patient access and patient retention compared to the current operations.

2.8 ED Categorization

This section reviews ways that EDs can be categorized, as well as the importance of categorization in healthcare. In 2006, the Institute of Medicine (IOM) recommended, in the "Future of Emergency Care" report, that emergency care should be categorized and regionalized while recognizing that no uniform system to categorize hospital emergency care services had been developed [30]. The IOM recommends that a standard national approach to the categorization of emergency care providers is needed and that the system should indicate meaningful differences in the types of available care but also be straightforward enough for organizations and the public to understand [15]. This sentiment echoed that of Boyd [31], who described a need to categorize hospitals because hospitals are not all equal in size, capability, commitment, patient population planning needs. Boyd also proposed categorizing hospitals as a way to rationally arrange scarce or expensive hospital resources. An appropriately categorized

EMS system can also expect cost and performance improvements regionally and within participating hospitals. There are many variations of categorization available throughout the literature.

Myers et al. [30] pursued a system to categorize emergency services and piloted the deployment of the system in Pennsylvania and Wisconsin. They developed a five-tiered ED categorization system that included limited, basic, advanced, comprehensive, and pediatric critical care emergency capabilities based on staffing and resources and then surveyed the hospitals in the two states to assess where they fit in the categorization system. The hospitals were then assigned a category based on the highest level of criteria that they achieved. Population access for each ED was also examined by assigning each census block group to the population weighted centre-point of the block group and then used the existing road network and ArcGIS software to calculate the travel time from each centre-point to varying types of EDs.

Kocher et al. [32] describe categorization as a process for inventorying, assessing, and cataloguing the emergency care resources and capacities in a region using a criteria-based classification system. Categorization can be done by having the facilities self-survey and self-declare, or by external survey and verification or by a combination of internal and external categorization. Categorization includes both vertical criteria related to clinical conditions and horizontal criteria based on ED capabilities and resources.

Vertical categorization is described by Kocher et al. to be related to clinical silos or the clinical conditions of a specific patient population and consists of categories such as comprehensive, advanced, basic, and limited services. Comprehensive emergency services include comprehensive ED and specialized inpatient intensive care, diagnostic, operative, and therapeutic services, and patients are rarely transferred for post-stabilization specialty care. Advanced emergency services include most of the services available for comprehensive services however they do occasionally transfer patients for post-stabilization specialty care [32]. Basic services involve basic ED and inpatient care, as well as select diagnostic, operative, and therapeutic services and equipment, with select specialized physicians available for consult. They often transfer some seriously ill patients, and most critically ill patients for stabilization and post-stabilization care. Limited emergency services have limited ED and inpatient care, as well as limited diagnostic services and equipment, and limited specialist physicians. They typically transfer seriously ill and critically ill patients to higher levels of care for stabilization and post-stabilization care.

In contrast, horizontal categorization relates to ED capabilities and the resources available to all types of patients, including those who do not fit in a disease specific vertical silo. Kocher et al. designate facility space, communication, equipment, diagnostic services, qualifications and availability of ED staff, and the availability of on-call specialists as critical issues for horizontal categorization. In the horizontal categorization scheme described by Kocher et al., a comprehensive ED consists of comprehensive ED services for a full range of medical conditions with 24/7 board-certified emergency physicians, access to specialized inpatient intensive care, and a rare need to transfer patients for post-stabilization care. Advanced ED services will provide advanced services for a wide range of medical conditions and have 24/7 coverage by emergency physicians as well as access to specialized inpatient intensive care and most specialized diagnostic, operative, and therapeutic services and equipment. Specialist physicians are either promptly available or on-call, and an advanced ED will occasionally transfer critically ill patients for post-stabilization care. A basic ED will provide services for a moderate range of medical conditions and has ED physicians on duty 24/7 with basic inpatient care as well as basic diagnostic, operative, and therapeutic services and equipment. Select specialist physicians are available on call, and seriously ill patients and most critically ill patients are often transferred for stabilization and post-stabilization care. A limited ED has services for a narrow range of medical conditions and the physicians are on-call 24/7. These EDs have little access to inpatient care, diagnostic, operative, and therapeutic services and equipment, and there are limited specialist physicians available for consultation. They will typically transfer seriously and critically ill patients to higher levels of care for stabilization and post-stabilization care.

An alternate four-tiered categorization scheme was proposed by Carr et al. [33] based on available resources and personnel. A comprehensive ED consisted of an immediately available emergency physician, a Computed Tomography (CT) scan, Intensive Care Unit (ICU), Operating Room (OR), cardiac catheterization with percutaneous coronary intervention capability within an hour, a broad array of consultants available within an hour, and additional consultants available outside of one hour. Advanced EDs had an immediately available attending physician, a CT scan, ICU, and OR available within an hour, and a limited array of consultants available within an hour. Basic EDs will have a physician available immediately, a CT scan within an hour, and a general surgeon available within an hour. A limited ED had a physician extender or physician available from home, a general surgeon available within an hour, and a CT scan available but not within one hour.

The IOM report “Emergency Medical Services: At the Crossroads” supports better coordination between the silos of healthcare, public health, and public safety [34]. They postulate that every hospital in a community can play a key role in the trauma system by being classified as a level I to level V trauma centre based on its capabilities. In this way, they suggest that trauma care can be optimized in a region through protocols and transfer agreements to direct patients to the most appropriate level of care based on their injury type and travel times.

2.9 Ambulance Location

This section reviews how ambulance base locations are chosen and how ambulance dispatching works. Goldberg [35] demonstrates that the dispatching of EMS calls is typically straightforward and the closest idle ambulance will be dispatched to the call. The objective is to get the appropriate equipment to emergencies in a safe and timely manner. Classic system operation begins with a 911 call and the call severity is estimated, the dispatcher will then evaluate the system and decide which vehicle(s) to send to the scene. When the vehicle arrives at the scene, service is provided and the vehicle may or may not transport the patient to a hospital, and the vehicle then becomes idle and returns to a predetermined location to wait for the next call. If the dispatching and vehicle location are not done well the system will be inefficient as both decision types are made in an active environment. Prior planning is done to develop dispatch strategies such as “send the closest idle vehicle”. When predetermined strategies are not appropriate, contingent strategies can be applied. Operations research is used to achieve assorted objectives such as minimizing the total or average time to serve all calls, minimizing the maximum travel to any single call, maximizing area coverage, or maximizing call coverage. Other objectives include minimizing cost, maximizing coverage equity, and maximizing labour equity. Typically, historical demand data is used to create models with the assumption that future demand will behave similarly.

According to Aboueljinane et al. [36] ambulance operations include both central and external operations. Central operations are performed at the dispatch centre by an operator who records the call information and makes an initial assessment, and a dispatcher who performs medical evaluation of the calls to determine which type of team should be deployed, and then dispatches the appropriate team to the call if required. External operations begin when the team is notified of the call. The team will gather their equipment and head to the vehicle where they will travel to the call location, find the patient, and provide care or prepare the patient for transport to a hospital. If the patient must be moved to a hospital, the dispatcher will determine a suitable destination where the patient will be transported and handed off to hospital staff for care. After handoff, the team will return to their base location.

Ambulance base locations are a crucial decision in the design of the EMS network. Ambulance bases typically correspond to existing facilities such as hospitals, fire stations, and police stations, however may also include “satellite garage” locations [36]. The location of these facilities is a topic explored using simulation studies. There is normally a designated response time as a legal or contractual goal that must be met. Bases are added and removed and compared in terms of cost and quality performance, as well as response times, and number of vehicles. Long term decisions include setting the service level and defining required skill sets, as well as determining the location and capacity of potential bases, while mid-term decisions include identifying the number of teams that are necessary at each base, as well as shift scheduling and vehicle scheduling. Short term decisions define the rules for dispatching available rescue teams to a call, choosing appropriate destination hospitals, and temporary repositioning or redeployment to provide coverage to incoming calls. Once a model of the system is created it is then verified and validated through animation, face validity or comparison to the real-world system.

Nogueira et al. [37] use an optimization model to locate the ambulance bases and allocate ambulances to each base, followed by a simulation model of the system to assess the behaviour after any changes. The optimization model was designed to minimize the response time, and experiments to determine better ambulance base locations were performed. The new locations were then used in a discrete event simulation to determine impacts to the system, and accurately approximate the response time. Typically, facility location problems will suggest the best locations to meet constraints and match the geographically distributed demand of customers. A simulation model was used to compare the response time from the optimization model to the response time of the simulation with the intent to increase the number of ambulances in the system, create new ambulance bases, reallocate existing ambulance bases, and create new hospitals [37]. The study concluded that the number of ambulances and the base locations impact the EMS system performance but that buying new ambulances and adding new bases do not necessarily create improvements. The study shows that increasing the number of ambulances at the bases to decrease the total number of bases may decrease the cost without decreasing performance.

Moeini et al. [38] review the static models for ambulance locating, including the LSCP and the MCLP. The LSCP aims to minimize the number of ambulances needed to cover all demand points however it does not permit locating more than one ambulance in a service centre. The MCLP was introduced as an improvement on the LSCP and tries to maximize the covered population using a predetermined number of ambulances. Both models are static and do not account for fluctuations in the EMS system such as when a call comes in and an ambulance is assigned, which causes problems if another call is received for the same service area as that area's ambulance will no longer be available for assignment. Several alternatives to the static models were suggested in the study.

The hierarchical objective set covering problem (HOSC) was introduced as a model that uses multiple coverage [38]. The HOSC model attempts to minimize the number of necessary ambulances needed to cover the demand while maximizing the multi-coverage of the zones, however it may lead to ambulance congestion. The maximal backup coverage models were proposed to overcome the difficulties in the HOSC, and use two ambulances to cover the demands. The Tandem Equipment Allocation Model (TEAM) uses two kinds of ambulances to cover the demands in a variation of multiple ambulance coverage.

A goal programming approach, the maximal-multiple location covering problem (MMLCP), was created to minimize the non-covered population and simultaneously maximize the multiple coverage obtained using a set number of ambulances [38]. The MMLCP can create congestion problems like those of the HOSC model. The double standard model (DSM) uses multiple ambulances to cover demands and requires that all demands are met within a specified response time, with an additional requirement that a specified proportion of the total demand must be covered within a different larger mandated response time.

Ambulance transports have also been used as a measure of system success. Smith et al. [39] investigated the impact on the EMS system including stress on surrounding hospitals when the Bellevue Hospital was closed by retrospectively reviewing EMS activity and 911 call types. They investigated the mean ambulance transports for the period that Bellevue was closed and compared these to the same period in the previous year. The surrounding hospitals received increased 911 ambulance transports with an increase of 63.6% at Mount Sinai Beth Israel, 60.7% at New York-Presbyterian/Weill Cornell Medical Center, and 37.2% at Mount Sinai Roosevelt. When Bellevue was reopened it could not participate in the 911 system for the first two months and then had its freestanding ED approved to receive 911 transports with restrictions from receiving trauma, cardiac arrest, third-trimester pregnancy, ST Segment Elevation Myocardial Infarction (STEMI), stroke, obvious surgical disease, emotional disturbance, and those in police custody until its inpatient services were fully restored. Even with these restrictions Bellevue received 37% of its baseline 911 transports which reduced the mean EMS transports to Mount Sinai Beth Israel. The database of 911 calls allowed for statistical analysis that could determine statistically significant changes in the 911 calls however the changes were clinically insignificant. The data showed that the changes in 911 transports can indicate signs of local and systemic stress. The study also identified that certain call types, such as difficulty breathing, unconsciousness, altered mental status, cardiac conditions, or pedestrian struck, required particularly rapid ambulance response and advanced resources that may strain the prehospital resources particularly as they tend to require extremely coordinated hand-offs between the prehospital treatment and the hospital staf f.

2.10 Discussion

This literature review highlights the use of analytical methods when designing EMS networks. The use of models to determine hospital locations allows for analysis of the entire system, and the consideration of regionalization and centralization in the network design assists with the distribution of resources. Measuring healthcare accessibility through spatial measure ensures that patient populations can travel reasonable distances to receive care. Evaluating the appropriateness of care within the ED provides insight into challenges for accessing primary care. The implementation of innovative solutions to provide emergency care, particularly in rural areas, is a way to reduce expensive resources while ensuring that patients receive the care they need. Analyzing patient flow and bed utilization within the ED provides awareness of where internal problems occur. ED categorization provides a method of cataloguing which services are available, as well as opportunities for coordination among different facilities. Ambulance care is an essential part of the EMS network and the use of modelling to determine base locations allows the system to provide care where there are large distances between ED sites, or from the population to the hospital, and to reduce travel times at the occurrence of an emergency. When these themes are considered in the design and improvement of EMS systems the system can be considered from a multi-criteria perspective to augment the provision of emergency care services.

Chapter 3 Data and Methods

This chapter discusses the data and methods used in this thesis. The data includes population, ED locations, and the Nova Scotia road network. This chapter explains ArcGIS and the Network Analyst extension and how these tools are used. The methods used to determine which population data was required and available are described, along with why the method that was chosen was used. This chapter also describes typical location-allocation models, as well as the specific models used in this thesis such as the P-median problem, the p-centre problem, the LSCP, and the MCLP.

3.1 ArcGIS

ArcGIS is a Geographic Information System which allows the user to use mapping and spatial reasoning to explore data [40]. A GIS is composed of computer hardware, software, geographic data, and people and is used to capture, manage, analyze, and display data and results. ArcGIS uses geospatial data which is data that has a place, an attribute, and optionally has a time [41]. It can be used for spatial analytics, mapping ang visualization, and data collection and management [40]. A common use for ArcGIS is for urban planners to analyze a community to determine suitable sites for development and construction.

ArcGIS deals with raster data or vector data. Raster data uses pixels to represent features such as satellite imagery, air photos, or scanned images [42] and is not used in this thesis. Vector data represents features as points, lines, or polygons as seen in Figure 3.1.

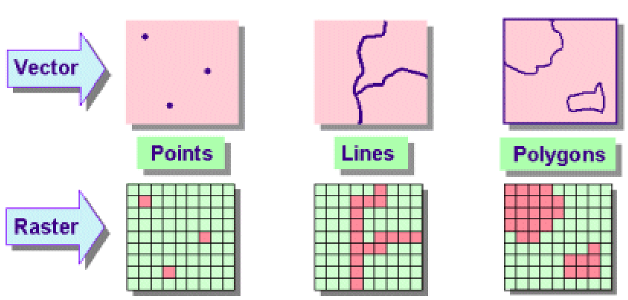

Figure 3.1 Vector and Raster Data [41]

In this project, an ED can be represented as a point, roads can be represented by lines, and the counties of NS can be represented using polygons. Vector data such as points, lines, and polygons are commonly saved as shapefiles in ArcGIS. A single shapefile can only contain one of the types of vector data and will store spatial data such as the location of the entity but also includes non-spatial descriptive data. For example, a point representing an ED will contain its latitude-longitude coordinates, but can also store the name of the ED, the phone number, and the ED categorization level. ArcGIS is used to determine and analyze the relationships between the different entities.

3.1.1 Network Analyst

The ArcGIS Network Analyst is an ArcGIS extension that allows the user to solve network problems including location-allocation problems, and service areas [43].

Location-allocation models are typically used to decide where to locate facilities such as warehouses, fire stations, ambulances among many others [44]. The requirements of a location-allocation problem include facilities, distances, and demand points. The demand points are typically weighted by population, property value, or other criteria dependant on the type of facility that is being located. Location-allocation models determine the optimal locations for the facilities based on distance and weight. Network Analyst can be used as a method to solve the location-allocation problem. It requires a road network, facilities, and demand points to solve location-allocation models. A formal definition of location-allocation models will follow in Section 3.3.4 .

The Network Analyst can also be used to generate service areas. A service area is the area which is within a prespecified distance by road from a facility. The Network Analyst can be used to generate service areas in desired increments such as 10-km, 20-km etc. For example, a 10-km service area boundary surrounding a facility demonstrates which roads are within 10-km of the facility. The demand points within the service area boundary can then be counted to determine which demand points or how many customers are served by the facility within 10-km. These service areas can be generated in the Network Analyst using roads and facilities.

The Network Analyst requires inputs including a transportation network, as well as parameters such as facilities, and demand points. A facility is the entity such as a hospital or warehouse that the user is trying to determine an optimal location for, and the customers are represented by demand points. The demand points can be weighted by population, property value, or other criteria. The ArcGIS Network Analyst parameter limits can be seen in Table 3.1.

Table 3.1 Network Analyst Parameters [45]

Network Analyst Parameter	Maximum Allowed
Facility	1,000
Demand Points	10,000

To solve a problem using Network Analyst the user must add at least one facility and one demand point [45]. The maximum number of facilities allowed is 1,000 and the maximum number of demand points is 10,000. When the parameter limits are exceeded the model becomes intractable and the software begins to run slowly, stall, or crash. Errors occur in network analyst when the facilities or demand points are not located along the transportation network [46].

The Location-Allocation solver in ArcGIS generates an Origin-Destination (OD) Cost Matrix of the minimum distance from each facility to demand point in the network [47]. This matrix is then used to heuristically solve the desired location-allocation model. The program uses Hillsman editing to edit the OD cost matrix, followed by semi-randomized solutions and a vertex substitution heuristic to create a group of good solutions. A metaheuristic then takes the group of good solutions and makes improvements until no improvement is possible and returns the best solution found to return near-optimal results.

ArcGIS is one tool for solving certain types of location-allocation problems, however they can also be solved in tools such as Excel Solver or CPLEX. ArcGIS is a useful tool as it can calculate the spatial components and has a tool for solving the location-allocation problems. However, the user could also calculate the distance between the demand points and the facilities using a GIS and model the location-allocation model in separate optimization software.

3.1.2 Roads

Solving the location-allocation problems or service area problems in ArcGIS requires there to be a road network. A network is defined as "a system of interconnected elements, such as edges (lines) and connecting junctions (points) that represent possible routes from one location to another" [48]. A road shapefile contains points (intersections or endpoints) and lines (road segments). This shapefile must be converted to a network dataset using another ArcGIS tool, ArcCatalog. Converting the road to a network dataset incorporates the connectivity properties of the roads such as one-way streets, intersections, bridges, and overpasses so the road network is representative of existing traffic rules and regulations.

For this project, the road file that was used is the Nova Scotia addressable road network that is available on the Nova Scotia Government's Open Data Portal [49]. This file was chosen as it is a road system that contains road information only where civic addressing exists. The file was originally a shapefile and then it was converted to a network dataset in ArcCatalog and used in Network Analyst.

Several problems occurred with the road network due to the geography of Nova Scotia. Brier Island and Long Island in Digby County were not connected to the road network as they use a ferry service which was not included. To rectify this, the ferry network from the Nova Scotia Topographic Database – Roads, Trails and Rails shapefile [50] was exported and connected to the addressable road network to ensure the larger islands were connected to the network and their populations could be accounted for in the location-allocation problems.

3.2 EDs

As discussed in the literature review in Chapter 2, there are many ED categorization methods found in literature. There are currently 37 EDs in NS: one tertiary, nine regional, 19 community, and eight CECs. The IWK Health Centre, a children's emergency department, has been excluded from analyses as it is located 1.2 km from the QEII. It is assumed that the IWK "co-exists" with the QEII due to their proximity and shared population.

The ED locations were pulled from the Nova Scotia Government's Open Data Portal and the file was added to ArcGIS [51]. Hospitals without EDs were removed from the file used for analyses. For the purposes of this research a tertiary, regional, or community site is considered a full-service ED and a CEC is not. The intent of a CEC is to provide access to primary healthcare while including capability for dealing with unexpected illness or injury in a timely manner [52]. Major emergencies are transported by EHS to a regional or tertiary centre [4]. A map of the NS EDs can be seen in Figure 3.2.

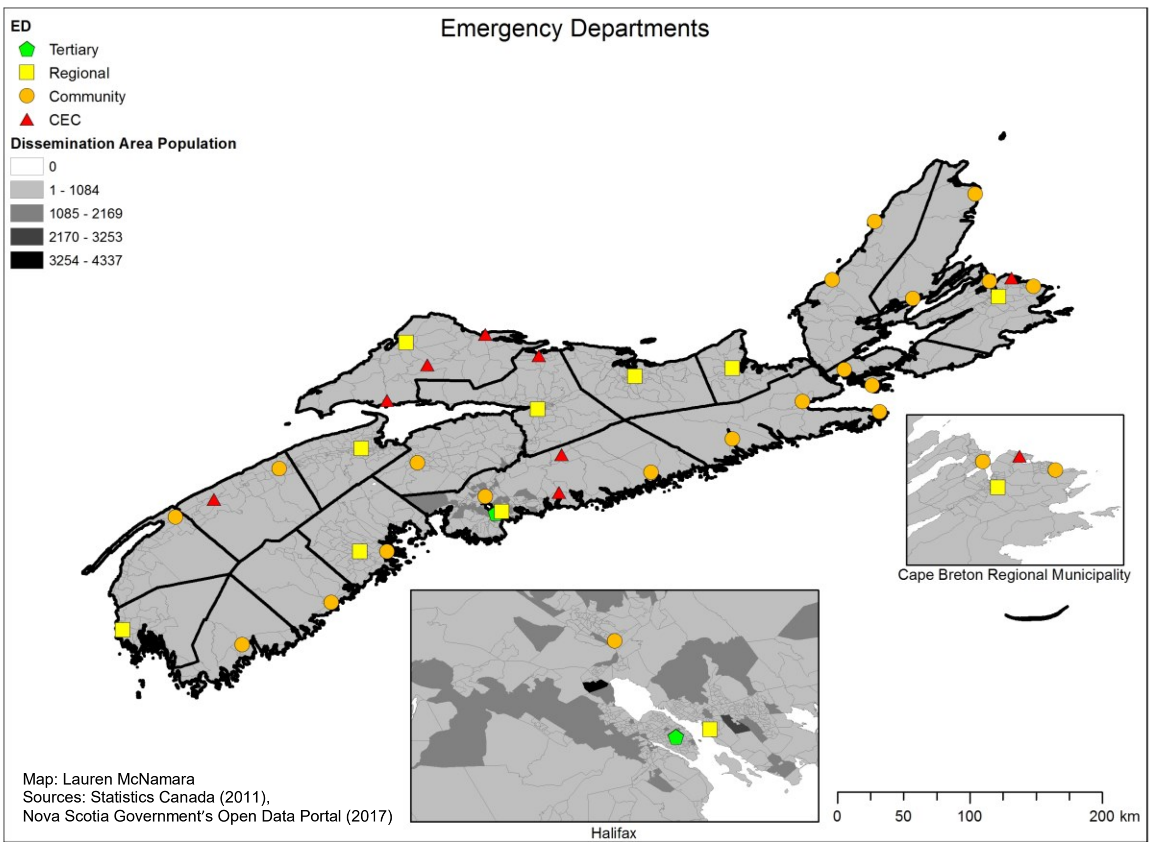

Figure 3.2 NS ED Map

3.3 Population

Historic demand for ED care was not available thus the population was used as a proxy. It is assumed that the population is homogeneous and that emergency care demand occurs proportionally with population density. For example, if geographic unit X has five times the population of geographic unity Y, then the demand will likewise be five times higher in unit X than unit Y

Nova Scotia has a population of 921,727 as recorded in the 2011 Statistics Canada Census. The breakdown of census units can be seen in Figure 3.3.

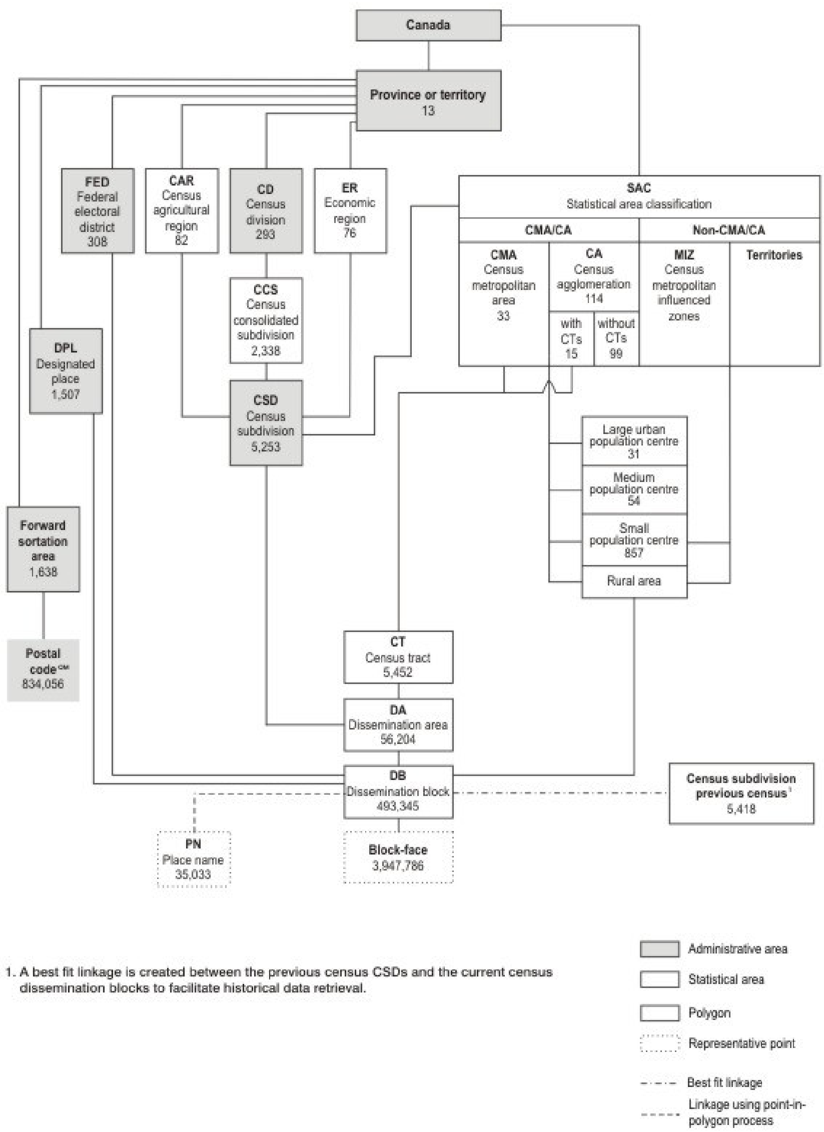

Figure 3.3 Statistics Canada Census Hierarchy [53]

In Nova Scotia, there are 18 Census Divisions which are more commonly known as counties. There are 1,645 dissemination areas (DAs) and a DA is defined by Statistics Canada as:

> “a small, relatively stable geographic unit composed of one or more adjacent dissemination blocks. It is the smallest standard geographic area for which all census data are disseminated. DAs cover all the territory of Canada [54].”

Although Statistics Canada defines a Dissemination Area as having a population of 400-700 there is some variation in Nova Scotia. The smallest DAs have a population of 5, and the largest has a population of 4,337 with an average DA population of 565. As this is the smallest standard geographic unit for which all census data are disseminated it was of investigated for this research.

The population throughout the province can be represented in multiple levels of aggregation. Several methods were considered in this thesis and outlined in Figure 3.4. The pros and cons of each representation will be discussed.

Figure 3.4 Population Representations

The location of individuals was considered as one way to indicate where the population of NS resides. Statistics Canada data is not available at an individual level and as there are 921,727 people in NS this was a cumbersome number to work with and greatly exceeds the 10,000-demand point restriction of the ArcGIS Network Analyst.

A more aggregated use of the individual population that was considered was to divide the population of the census DAs over the number of buildings in each DA to get a population density in terms of population per building. There are 547,290 buildings in NS [55] which again exceeds the 10,000-demand point limit of the Network Analyst and hence is slow to load, and difficult to work with.

3.3.1 Dissemination Area Centroid

A method that was considered to represent the location of people within Nova Scotia was to use the geographic centroid of census DAs. As there are 1,645 DAs within NS this gives 1,645 demand points. The geographic centre of the DA unit is considered the point where all the people within that unit reside. Each point can be weighted by the DA population. This is an approximation as it is known that the entire population would not live at the same point. This method is a small enough number and fits within the Network Analyst limit of 10,000 demand points. It is also the smallest standard unit where all census data is available that is released by Statistics Canada.

3.3.2 Community Clusters

Community Clusters are a new geographic unit developed by the Nova Scotia Health Atlas and are defined as “Newly developed area units based on aggregated census dissemination areas intended to align as close as possible with community activity” and consist of approximately 27,000 to 51,000 people [56]. These clusters are an aggregation of census DAs and are therefore a less refined unit for analysis as there are only 54 community clusters throughout the province. Community clusters can be aggregated to form the 14 Community Health Networks which can be aggregated again to form the four NSHA management zones.

3.3.3 Latitude-Longitude Grid

Another method that was considered was the population density with an overlaid latitude-longitude. This method results in arbitrarily defined grids which could cause towns or communities to be split which would not make sense in practice.

3.3.4 Chosen Population Representation

The selection of the group size for use in analyses is important. Using too few groups will be too aggregate and will lose information. In contrast, too many groups may not be tractable or may over fit the solution. An arbitrary grouping may have strange boundaries, such as splitting a town into two when both halves should remain together. A measure that makes for good grouping must be aggregate enough to be solvable, yet numerous enough to fit the solution. Data availability and the use of a standard measure also help to determine a good group. As such, the method that was chosen for use in these analyses are the Dissemination Area Centroids. This method is aggregated enough to be easy to manipulate and have relatively quick run times in the ArcGIS Network Analyst, yet small enough to accurately demonstrate where the populations reside. The individual population and buildings were overly large and difficult to work with. The community clusters are too aggregated, as with 54 community clusters and 37 EDs the model would not be very realistic.

The dissemination area centroids were calculated using data from Statistics Canada, as well as ArcGIS tools. The dissemination area tabular data was retrieved from the Canadian Census Analyser through Dalhousie University's Data Liberation Initiative. The 2011 Census Dissemination Area data for Nova Scotia was downloaded. This file contains the population for each of the 1,645 DAs in the province. Of the 1,645 DAs, 15 have no population, and 1,630 are populated.

The 2011 Dissemination Area Cartographic Boundary File was then added as a shapefile to ArcGIS [57]. In ArcGIS, the Nova Scotia DA boundaries were extracted and then joined to the tabular data. This connected the geographic boundary to the population for each of Nova Scotia's dissemination areas.

The geographic centre point of each DA was then computed in ArcGIS and used as an approximation for where the population of the DA lives. The geographic centroid was moved to the closest road network using the Near tool in ArcGIS as seen in Figure 3.5. Hereafter, the repositioned Dissemination Area centroids are referred to as DA points.

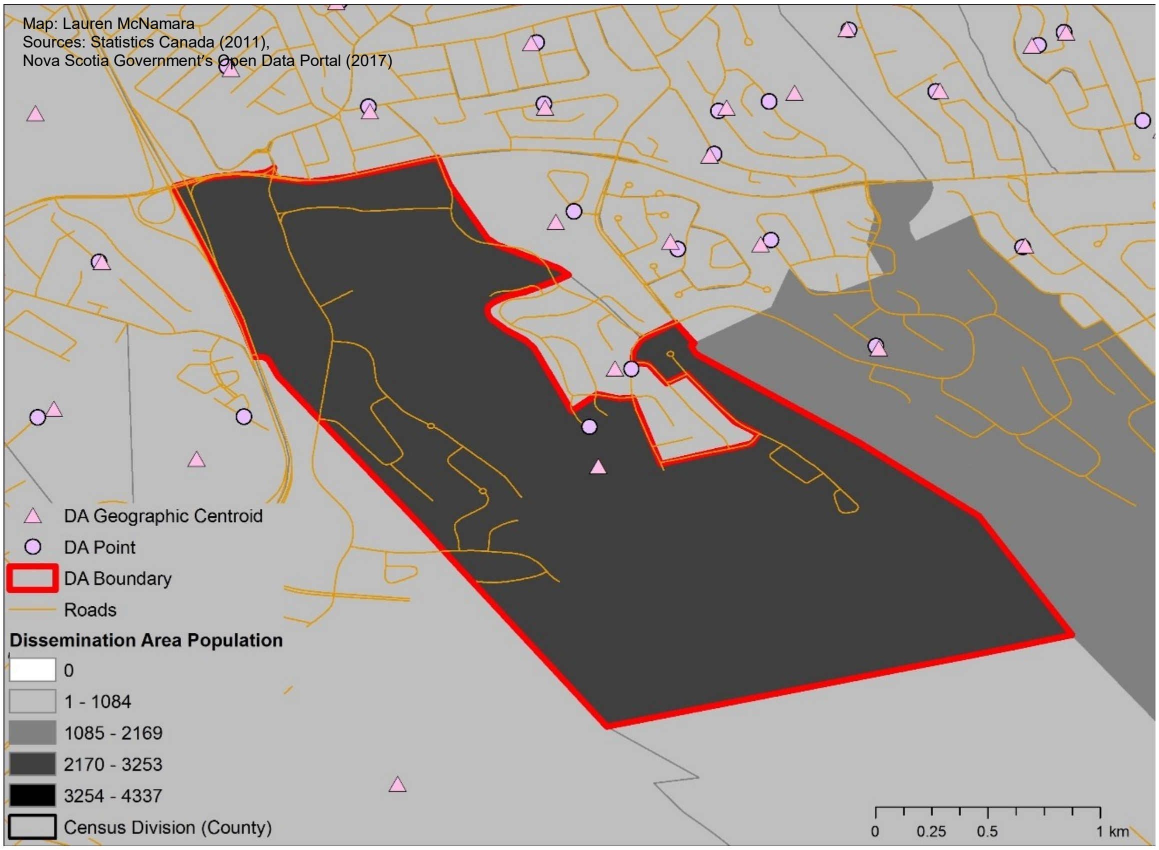

Figure 3.5 DA Location Point

This method is adapted from methods used in the literature. A study was performed on the location of helicopter emergency medical services in Norway using the population-weighted centroid of each of Norway's 428 municipalities [58]. A DA point was calculated for each DA in Nova Scotia and can be seen in Figure 3.6.

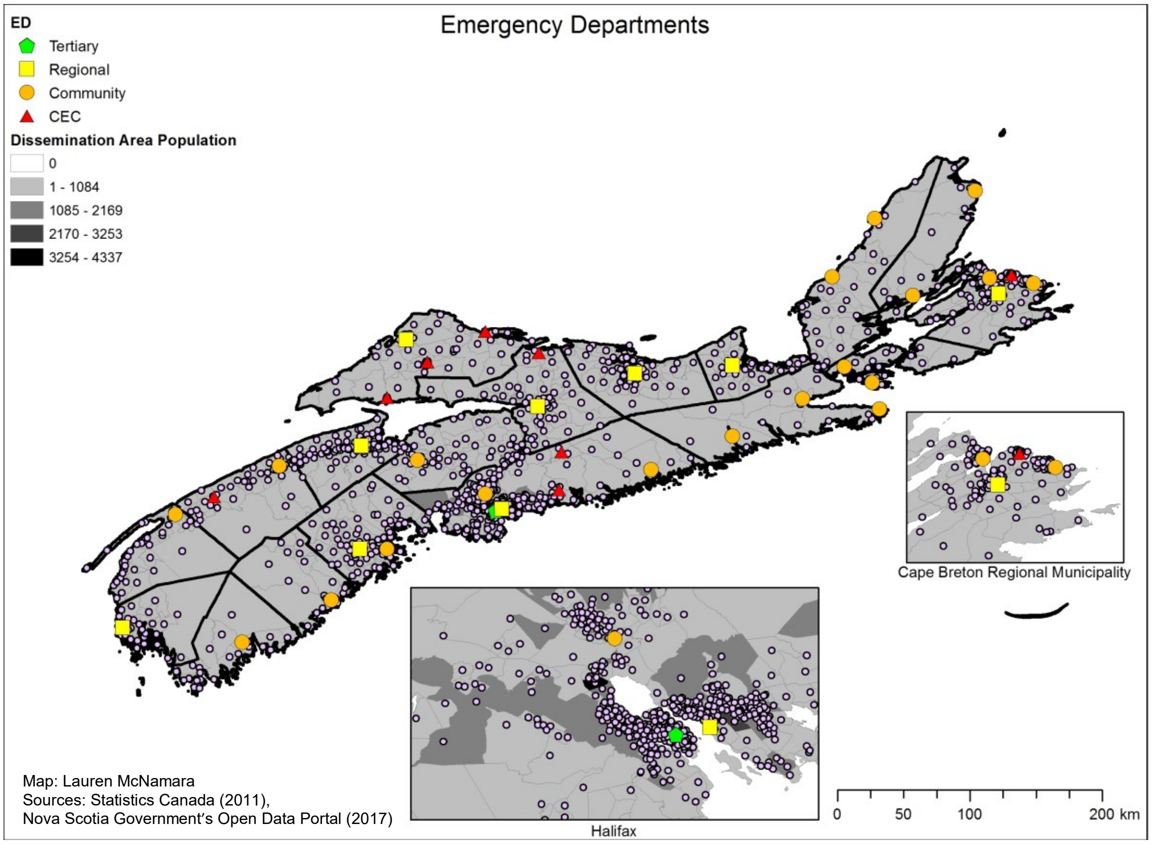

Figure 3.6 DA Points

3.4 Location-Allocation

Decisions relating to locations depend on quantitative criteria such as distances but can also rely on more intangible criteria described in [44] such as the perceived quality of an area, or a historical allegiance to a certain facility. There are differences among industries about where to locate facilities. For example, there are differences between the extraction industry including agriculture and mining, and the service industry. The ore extracted at a gold mine would not be transported close to the customer to extract the gold at that site. In contrast, the service industry is required to have sites near the demand to serve its customers.

An issue described in [44] that arises in the location of facilities is whether the service chooses the customer, or whether the customer chooses the service. Shipping or allocation models typically involve the firm choosing the facility the customer is being served from. For example, if a customer makes an online order, the firm will choose where the product will be shipped from and what trucks will be used. The customer has no choice in the shipping decisions but they will still receive their ordered product. A contrasting model is the customer choice or shopping model. For example, if a customer lives close to two different grocery stores, grocery store A and grocery store B, they can choose which store to go to. This decision could be based on what is on sale in the flyer at each store, or it could be based on a historical family allegiance to a specific grocery store. In this case, the grocery store can market and try to convince customers to come to their store but it is ultimately the customer's choice.

The objective of the location of public services such as a hospital is to make the hospital accessible to as many people as possible such that the distance between the facility and the customer is as short as possible. This can be done by trying to make the average distance between the facility and customer as short as possible to promote accessibility [44]. Another method, typically used by shipping companies, is trying to locate a distribution centre to minimize make the sum of the distances from the customer to the facility to reduce costs. Several types of location-allocation models will be explored in the following sections.

A unique feature of the emergency care system model in Nova Scotia is that the EDs are located such that the population should have good access to the facility, however the patient/customer does have choice about which facility they choose to use. If they are arriving by ambulance they will not have a choice, however if they decide they need to go to the ED they do have the freedom to choose whichever ED they prefer.

In this Section, we now review the common location-allocation models found in literature. This includes the p-median problem, p-centre problem, LSCP, and MCLP.

3.4.1 P-median problem

3.4.1.1 Formulation

One type of location-allocation model used in this research is the un-capacitated p-median problem which aims to optimize the minimum travel distance weighted by population density. This model uses a finite number of facilities and typically determines their location [12]. The p-median problem finds the location for each facility that results in the minimum travel distance by road for the customers weighted by population density [11].

The p-median problem requires a given number of facilities, *p*, to be located such that each customer is served by the closest facility and the total travel distance or transportation cost is minimized [44].

The p-median problem formulation [44]:

$$Min\ Z = \sum_i \sum_j w_i d_{ij} x_{ij}$$

Subject to:

$$x_{ij} \le y_j,\ \forall i, j$$

$$\sum_j y_j = p$$

$$\sum_j x_{ij} = 1,\ \forall i$$

$$x_{ij}, y_j \in \{0,1\}$$

Where:

$i = \{1, \dots, m\}$: number of customers

$j = \{1, \dots, n\}$: number of facilities

w_i: Demand weight at point i

d_{ij}: distance from demand i to facility location j

$$x_{ij} = 1 \text{ if demand } i \text{ is assigned to facility location } j$$

$$y_j = 1 \text{ if facility is located at } j$$

$$p\text{: number of facilities to locate}$$

3.4.1.2 Application

This model is applied to the Nova Scotia emergency care system as follows. In the NS ED system, there are *p* facilities to locate (*p* = 37 EDs). The ED locations are represented by $y_1, y_2, \ldots, y_n$ where *n* = 37 in the NS baseline analysis. Customer *i,* represents a DA point, and is served by facility *j* if the assignment variable x_{ij} is equal to one. There are 1,630 DA points (*m* = 1,630). The distance between the customer and the ED is represented by d_{ij} and is calculated using ArcGIS.

The location of the EDs in Nova Scotia are known so when we are measuring the current state of the system the facility locations are known in the p-median model. Since both the population, and the locations are known, the model is used to assign DAs to their closest ED. In Section 4.1 , we use the p-median model to determine the location of additional EDs.

In ArcGIS, the DA points are used as demand points and are weighted by population. The EDs with their designated locations are used as the facilities. An example of the assignment of DAs to an ED can be seen in Figure 3.7.

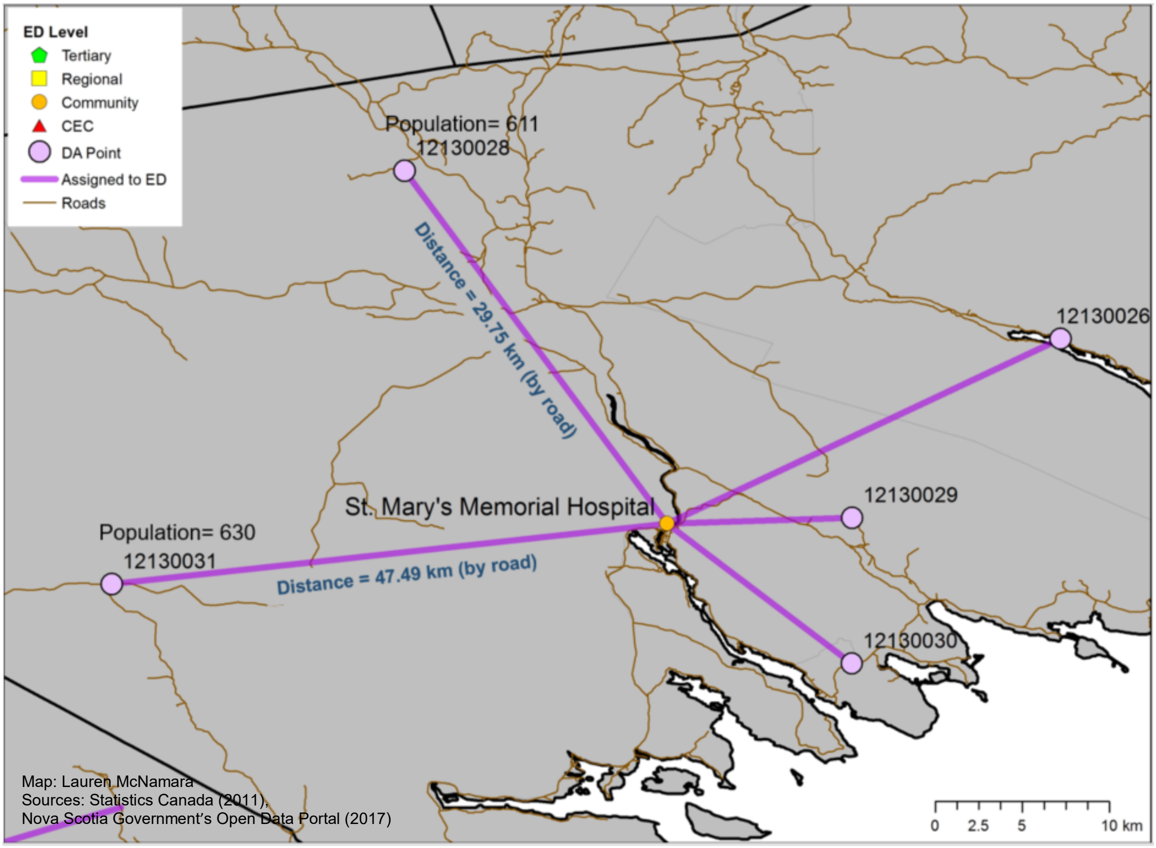

Figure 3.7 St. Mary's Memorial Hospital P-median Assignment

The DA population is used to weight the DA point, the distance along the road network is measured, and the population is then multiplied by the distance to get the resulting population-weighted distance as seen in Table 3.2.

Table 3.2 St. Mary's Memorial Hospital P-median Assignment Summary

DA	Population	Distance (km)	Population-Weighted Distance
12130028	611	29.75	18,180.29
12130031	630	47.49	29,918.92

3.4.2 P-centre Problem

3.4.2.1 Formulation

The objective of the un-capacitated p-centre problem is to minimize the furthest distance (maximum distance) that any person must travel [11]. Each demand is met by one facility and there is a predetermined number of facilities [11]. The p-centre problem focuses on the worst-case distance from customer to facility [44]. A weighted version of the P-centre problem does exist but was not included in this research as we were interested in the worst-served distance alone.

The p-centre problem formulation [59]:

$$Min\ Z$$

Subject to:

$$\sum_j x_{ij} = 1,\ \forall i$$

$$\sum_j y_j \le p$$

$$x_{ij} \le y_j,\ \forall i, j$$

$$\sum_j d_{ij} x_{ij} \le Z, \forall i$$

$$x_{ij}, y_j \in \{0,1\}$$

Where:

$i = \{1, \dots, m\}$: number of customers

$j = \{1, \dots, n\}$: number of facilities

d_{ij}: distance from demand i to facility location j

p: number of facilities to locate

$x_{ij} = 1$ if demand i is assigned to facility location j

$y_j = 1$ if facility is located at j

The p-centre problem was adapted as a measure of how good or bad each ED serves its assigned population.

3.4.2.2 Application

The metric that is used to measure the worst distance from customer to facility in the NS model is the DA point to ED distance. This can be shown for each ED, and for the worst overall, or longest DA point to ED distance. In the NS model, the EDs have known fixed locations, and the DAs also have known fixed locations. The p-centre problem therefore is the measure of the worst distance from a DA to the closest ED for each ED and overall.

When the current state of the system is being measured, the p-centre problem will have $p = 37$ which forces the locations of the EDs to be the existing ED sites. The DA points are known and the p-centre problem will then assign the DAs to the closest ED.

3.4.3 Location Set Covering Problem (LSCP)

3.4.3.1 Formulation

The purpose of the LSCP is to minimize the number of facilities that are located while ensuring that each customer is within a specified service distance or time of a facility [44]. For example, a decision could be made based on a standard, such as the 2014 Nova Scotia Emergency Care Standards dictating that:

> "A 24/7 Emergency Department should be accessible within approximately one hour's drive under average driving conditions for 95 per cent of the residents of Nova Scotia [6]."

The formulation of the LSCP [44]:

$$Min\ Z = \sum_{j} y_j$$

Subject to:

$$\sum_{j \in N_i} y_j \geq 1,\ \forall i$$

$$y_j \in \{0,1\}$$

Where:

$$i \in I\text{: Set of demands}$$

$$j \in J\text{: Set of facility locations}$$

$$S\text{: specified service distance}$$

$$N_i = \{ j \in J | d_{ij} \le S \},\ \forall i$$

$$d_{ij}\text{: distance from demand } i \text{ to location } j$$

$$y_j = 1 \text{ if a facility is located at } j$$

The objective of the formulation is to minimize the total number of facilities such that every demand is covered within the specified distance, *S*.

3.4.3.2 Application

The location of the facilities, y_j, represents the locations of the existing EDs and is known. A demand point, *i*, can be covered by facility *j* if it is within the set N_i of demands accessible from facility *j* within the specified service distance *S*. The demand points, *i*, are assigned to EDs, *j*, to minimize the number of facilities such that every demand point or DA centroid is covered within the specified service distance.

This problem can be modeled in the ArcGIS Network Analyst using the location-allocation model called “Minimize facilities/maximize coverage”. This tool requires the EDs to be added as the facility, and the DA points to be added as the demand points, weighted by population. This model will be revisited in 4.6 .

3.4.4 Maximal Covering Location Problem (MCLP)

3.4.4.1 Formulation

The un-capacitated MCLP locates a specified number of facilities, *p*, such that the total weight that can be covered within a given distance from the facilities is maximized [44]. It chooses a location for each facility that results in the fewest people residing outside of a desired service distance

The MCLP Formulation [60] :

$$Max\ Z = \sum_{i} w_i x_i$$

Subject to:

$$\sum_{j \in N_i} y_j \geq x_i,\ \forall i$$

$$\sum_{j \in J} y_j = p,\ \forall j$$

$$x_i \in \{0,1\}$$

$$y_j \in \{0,1\}$$

Where:

$i \in I$: Set of demands

$j \in J$: Set of facility locations

w_i: Demand weight at point i

$x_i = 1$ if demand at node i is covered

$y_j = 1$ if facility is located at j

p: $n$umber of facilities to locate

$$N_i = \{j \in J \mid d_{ij} \leq S\},\ \forall i$$

d_{ij}: distance from demand i to location j

The objective of the MCLP is to maximize the weight if the customer is within the prescribed distance such that the number of facilities is equal to the prescribed number of facilities.

3.4.4.2 Application

In the model of the NS Emergency System, the locations of the EDs are known and fixed and there are *p* facilities to locate, or *p* = 37 EDs. The ED locations are represented by $y_1, y_2, \ldots, y_n$ where *n* = 37 in the NS baseline analysis. If customer *i,* represented by a DA point is served by facility *j,* the assignment variable x_{ij} is equal to one. The MCLP measures the population within a service distance, *S*, measured in kilometres.

In ArcGIS, the MCLP model can be measured using service areas. The distance within the specified distance *S* from the facility is referred to as a Service Area. A Service Area is a polygon with the facility at the centre that measures a specified distance along the roads. For example, a 10-km service area for an ED includes all the roads within *S* = 10-km of the ED. An extension of this is to count all the population demand points within this polygon. In the service area method that was used, a DA can be in only one ED service area (no overlapping service areas). An example of the service area calculated for the Yarmouth Regional Hospital can be seen in Figure 3.8.

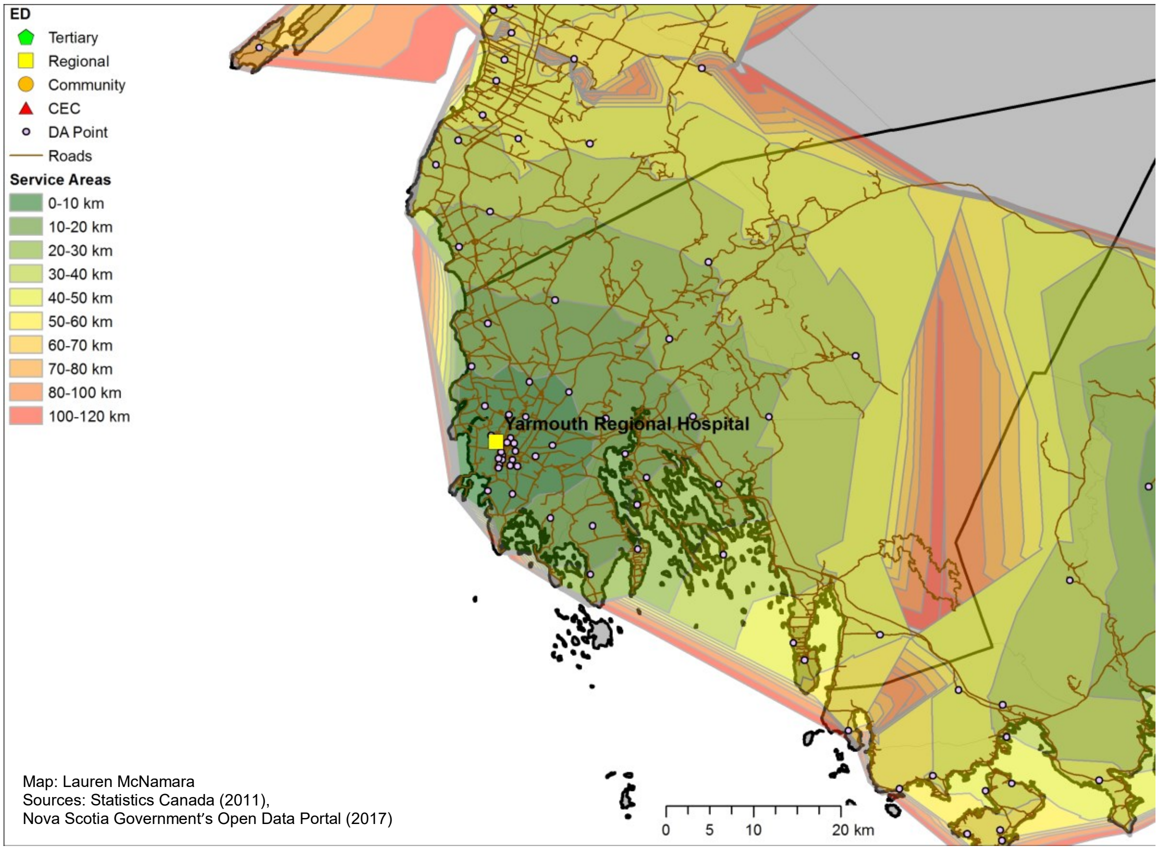

Figure 3.8 Yarmouth Regional Hospital Service Area

The DA points were then counted for each service area and the population was summed as seen in Table 3.3.

Table 3.3 Yarmouth Regional Hospital Service Area Summary

Distance from ED (km)	Population	% of Total Population	Number of DAs
0-10	12,749	1.38%	25
10-20	4,928	0.53%	9
20-30	3,670	0.40%	6
30-40	3,568	0.39%	6
40-50	4,675	0.51%	8
50-60	473	0.05%	1
60-70	413	0.04%	1
Sub-total	**30,476**	**3.31%**	**56**

The maximize coverage option in the Network Analyst Location-Allocation tool does the same thing as a Service Area and could be used to create the same measures. The results are displayed differently, however the assignment of the DAs to the EDs seen in Figure 3.9 using the maximize coverage tool are the same as the results shown in Figure 3.10 using the Service Areas. Both assignments use a service distance S = 72 km.

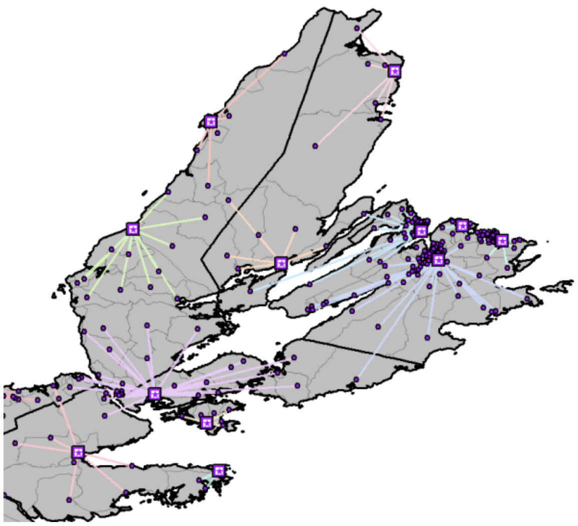

Figure 3.9 MCLP - Maximize Coverage

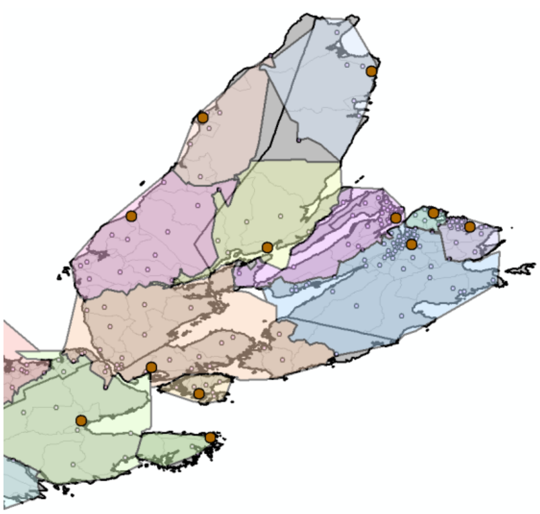

Figure 3.10 MCLP - Service Area

Chapter 4 Summary Statistics

This chapter explores the results of the analyses performed using the data and methods from Chapter 3. First, the results of the p-median problem applied to the Nova Scotia Emergency system are explored. This is followed by the p-centre problem and MCLP results. Also included are analyses involving measuring the distances between the EDs. Further analyses measuring the system impacts of adding or removing EDs are also included. Measures of ED redundancy are investigated and benchmarking to other provinces is explored.

4.1 P-median Problem Results

This assignment of DAs to EDs was done for the entire province using the p-median problem as seen in Figure 3.2.

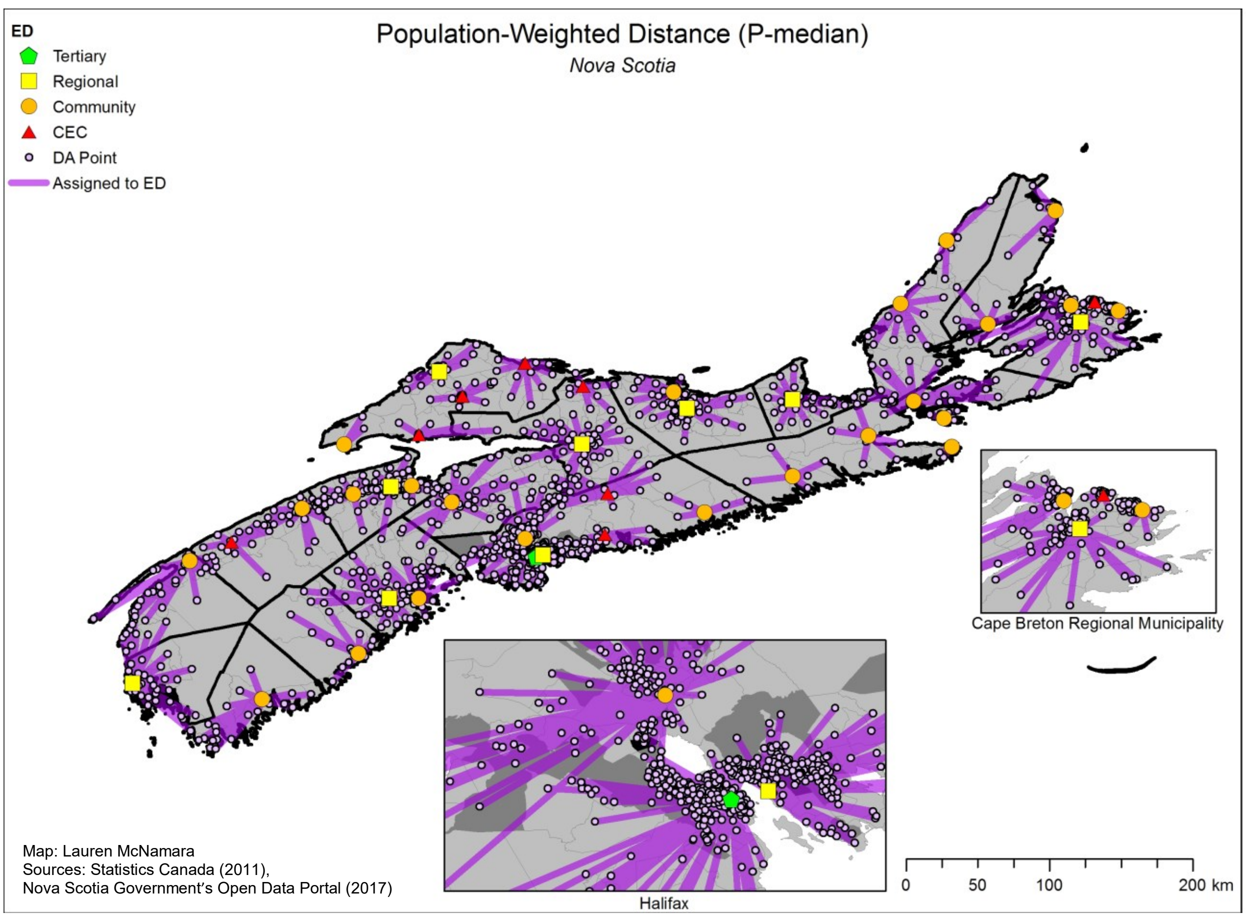

Figure 4.1 P-median Problem: DA Assigned to ED

The resulting population-weighted distance distribution is in Table 4.1.

Table 4.1 P-median Population-Weighted Distance Summary

Total Population-Weighted Distance	Population	% of Total Population	Number of DAs
0-5,000	448,233	48.63%	877
5,000-10,000	210,402	22.83%	351
10,000-15,000	118,867	12.90%	196
15,000-20,000	64,398	6.99%	99
20,000-25,000	34,200	3.71%	55
25,000-30,000	18,861	2.05%	25
30,000-35,000	10,029	1.09%	13
35,000-40,000	8,126	0.88%	6
40,000-45,000	3,905	0.42%	4
45,000-50,000	1,795	0.19%	2
50,000-55,000	0	0.00%	0
55,000-60,000	2,911	0.32%	2
Grand Total	**921,727**	**100.00%**	**1,630**

This table shows that most of the population is within 5,000 population-weighted km of an ED. For context, a Dissemination Area point with a population of 580 (DA 12090936) falls on University Avenue in Halifax between Robie Street and Summer Street. This DA is 0.9 km from the QEII which results in a population-weighted distance of 532.6 which puts the DA in the 0-5,000 bin.

A summary of other results is in Table 4.2.

Table 4.2 P-median Summary

	ED Population	DA Population-Weighted Distance	ED Population-Weighted Distance
Average	24,912	7,062	311,109
Minimum	1,348	9	5,646
Maximum	159,724	55,605	1,612,195
Total	**921,727**	**11,511,037**	**11,511,037**

This table shows that the average ED population is 24,912, the minimum is 1,348, and the maximum is 159,724. The average DA to ED population-weighted distance is 7,062 population-weighted km. The minimum population-weighted distance for a DA to ED is 9 population-weighted km and corresponds to DA 12090587 which is assigned to Eastern Shore Memorial Hospital. The maximum is 55,605 population weighted km which corresponds to DA 12020085 which is assigned to Yarmouth Regional Hospital.

The sum of each DA to ED population-weighted distance results in the overall population-weighted distance of the system which is 11,511,037 population-weighted km. The sum of the DA to ED population-weighted distance at each ED is called the ED population-weighted distance. The ED with the smallest assigned population-weighted distance has 5,646 population-weighted km assigned, the largest has 1,612,195 population-weighted km assigned, and the average is 311,109 population-weighted km. The Dissemination Areas with the 10 largest population-weighted distances can be seen in Table 4.3.

Table 4.3 Largest DA Population-Weighted Distance

DA	Population	Distance (km)	Population -Weighted Distance	ED Level	Assigned to ED
12060151	803	48.32	38,803.75	Community	Cobequid Community Health Centre
12080072	889	43.82	38,953.40	Community	Cobequid Community Health Centre
12180025	562	71.42	40,139.00	Community	Buchanan Memorial Community Health Centre
12080062	1,375	29.94	41,165.76	CEC	Musquodoboit Valley Memorial Hospital
12090925	1,148	36.15	41,503.03	Community	Cobequid Community Health Centre
12030056	820	51.81	42,482.74	Community	Digby General Hospital
12010050	820	56.49	46,320.03	Community	Roseway Hospital
12010044	975	49.15	47,916.41	Community	Roseway Hospital
12090678	1,747	31.58	55,176.20	Community	Cobequid Community Health Centre
12020085	1,164	47.77	55,604.98	Regional	Yarmouth Regional Hospital

This table shows that DA 12020085 which is assigned to Yarmouth Regional Hospital has the highest population-weighted distance. It has a higher than average population of 1164 that is travelling 47.77 km resulting in a high population weighted distance.

4.1.1 System Changes

As an extension, the model was run using different numbers of EDs. The maximum distance from a DA to an ED was computed as a function of the number of EDs. For the range of 1 to 37 EDs, the existing EDs and their locations were inputted into the p-median problem as candidate ED locations. For scenarios with greater than 37 EDs, DA points were inputted into the model as candidate ED locations. The ED locations were selected optimally using the p-median problem to best satisfy the objective of minimizing the population weighted distance. The p-median problem was used as it aims to minimize the population-weighted distance of the overall system. The furthest DA to ED distance shown is the worst-served distance of the overall system. The results are displayed in Figure 4.2 and show what happens to the maximum DA to ED distance with varying numbers of EDs.

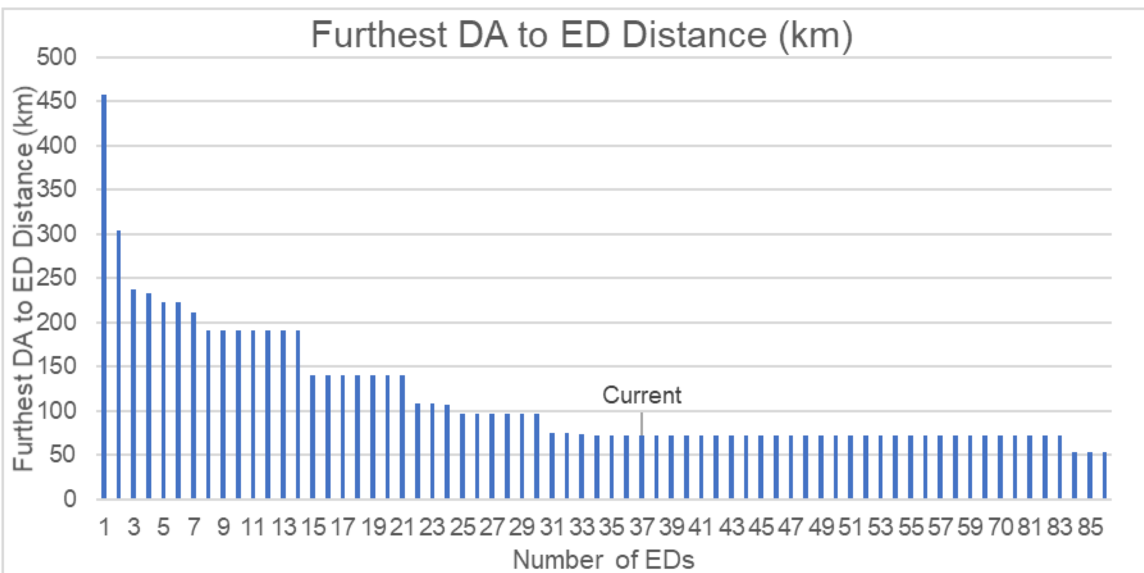

Figure 4.2 Furthest DA to ED Distance vs Number of EDs

With the current arrangement of 37 EDs the maximum DA to ED distance is 71.42 km. This is not improved by adding EDs until 84 EDs are located when the distance drops to 52.77 km. Furthermore, the maximum distance does not increase substantially until the network has less than 31 EDs.

The objective of the p-median problem is to minimize the population-weighted distance of the overall system. As EDs are added to the system in Figure 4.2 they are added to meet this objective. The model has not added an ED close to the furthest DA as this would be adding an ED close to the individual point and would not have as great of an impact on the overall system's population-weighted distance.

The model indicates that if an additional ED was added to the network that it should be near Elmsdale based on population and distance. The model also identifies Eastern Memorial Hospital as the site that should be removed based on population-weighted distance should 36 EDs be desired. Please note that the model is not capacitated and does not account for the type of the new ED.

4.2 P-centre Problem Results

The p-centre problem model was run to assign DAs to the closest ED. The p-centre problem makes this assignment such that the worst-served DA (based on the maximum distance from DA to ED) is minimized. The shortest distance from a DA to an ED is 0.02 km and this corresponds to DA 12090638 which is assigned to Cobequid Community Health Centre, and the longest distance from a DA to an ED is 71.42 km which corresponds to DA 12180025 which is assigned to Buchanan Memorial Community Health Centre. The average distance from a DA to an ED is 12.77 km. This summary can be seen in Table 4.4.

Table 4.4 Worst-Served DA per ED

ED	ED Level	Maximum DA to ED Distance (km)
New Waterford Consolidated Hospital	CEC	9.38
St. Anne's Community and Nursing	Community	10.45
Eastern Memorial Hospital	Community	13.18
Glace Bay Health Care Facility	Community	21.91
Dartmouth General Hospital	Regional	21.96
All Saints Springhill Hospital	CEC	25.46
Twin Oaks Memorial Hospital	CEC	30.04
St. Martha's Regional Hospital	Regional	30.18
Annapolis Community Health Centre	CEC	34.53
Guysborough Memorial Hospital	Community	34.75
Lillian Fraser Memorial Hospital	CEC	35.15
Eastern Shore Memorial Hospital	Community	35.51
North Cumberland Memorial Hospital	CEC	35.90

ED	ED Level	Maximum DA to ED Distance (km)
QEII - Halifax Infirmary Site	Tertiary	36.17
Cumberland Regional Health Care Centre	Regional	37.41
Soldiers' Memorial Hospital	Community	38.43
Musquodoboit Valley Memorial Hospital	CEC	38.50
Aberdeen Hospital	Regional	39.39
Victoria County Memorial Hospital	Community	41.17
Inverness Consolidated Memorial Hospital	Community	43.16
St. Mary's Memorial Hospital	Community	47.49
South Cumberland Community Care Centre	CEC	47.68
Cobequid Community Health Centre	Community	48.32
Colchester East Hants Health Centre	Regional	49.77
South Shore Regional Hospital	Regional	51.89
Sacred Heart Community Health Centre	Community	52.78
Strait Richmond Hospital	Community	52.81
Valley Regional Hospital	Regional	53.26
Hants Community Hospital	Community	56.00
Roseway Hospital	Community	56.49
Yarmouth Regional Hospital	Regional	59.54
Fishermen's Memorial Hospital	Community	60.86
Queens General Hospital	Community	65.35
Northside General Hospital	Community	65.83
Cape Breton Regional Hospital	Regional	67.50
Digby General Hospital	Community	70.11
Buchanan Memorial Community Health Centre	Community	71.42

The longest distance from the DA point to the ED from Buchanan Memorial Community Health Centre is 71.42 km whereas the longest distance from a DA point to the ED for New Waterford Consolidated Hospital is 9.38 km. This means that the person travelling the furthest to reach Buchanan Memorial must travel much further than the furthest person travelling to New Waterford. The average maximum DA to ED distance is 42.97 km which means that the worst served DA is on average 42.97 km from its closest ED.

The 10 longest DA-to-ED distances can be seen in Table 4.5.

Table 4.5 Longest DA to ED Distance

DA	Population	Distance (km)	ED Level	Assigned to ED
12030069	413	55.08	Regional	Yarmouth Regional Hospital
12080110	485	56.00	Community	Hants Community Hospital
12010050	820	56.49	Community	Roseway Hospital
12010045	473	59.54	Regional	Yarmouth Regional Hospital
12060153	624	60.86	Community	Fishermen's Memorial Hospital
12040029	420	65.35	Community	Queens General Hospital
12180032	502	65.83	Community	Northside General Hospital
12160017	464	67.50	Regional	Cape Breton Regional Hospital
12030057	234	70.11	Community	Digby General Hospital
12180025	562	71.42	Community	Buchanan Memorial Community Health Centre

4.3 MCLP Results

The MCLP is used to measure the population within specified service distances of each ED throughout the provinces. Service areas were generated throughout the entire province using the existing 37 EDs and breaks at 10-, 20-, 30-, 40-, 50-, 60-, 70-, 80-, 100- and 120-km. A service distance is the distance by road containing the population assigned to an ED. For example, a 10-km service area would encompass all the population that lives within 10-km of an ED. This allows us to measure how many people live close to an ED. The results can be seen in Figure 4.3 and Table 4.6.

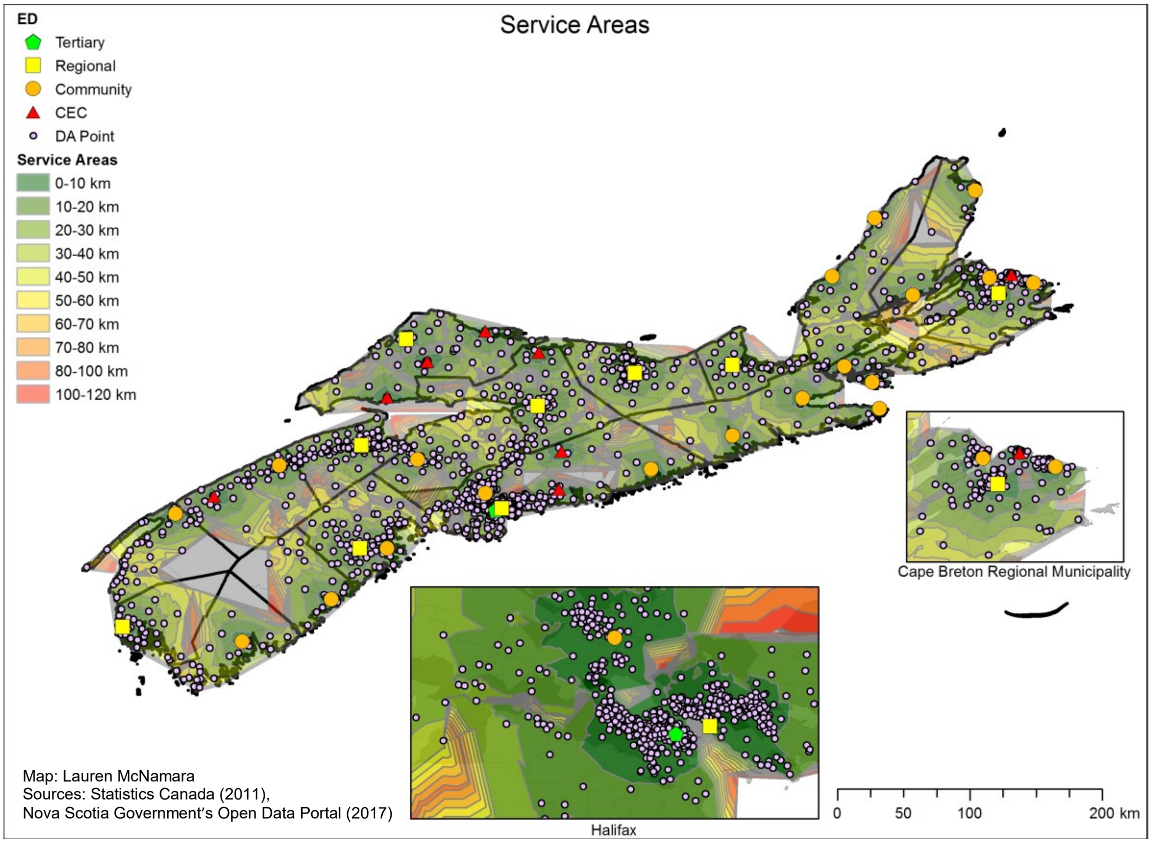

Figure 4.3 NS Service Areas

Table 4.6 NS Service Area Summary

Distance from ED (km)	Population	% of Total Population	Cumulative % of Total Population	Number of DAs
0-10	553,707	60.07%	60.07%	959
10-20	172,913	18.76%	78.83%	305
20-30	96,053	10.42%	89.25%	178
30-40	56,986	6.18%	95.44%	108
40-50	27,369	2.97%	98.41%	51
50-60	8,215	0.89%	99.30%	16
60-70	4,097	0.44%	99.74%	8
70-80	647	0.07%	99.81%	2
80-100	1,178	0.13%	99.94%	2
100-120	562	0.06%	100.00%	1
Grand Total	**921,727**	**100.00%**	**100.00%**	**1,630**

This shows that 60% of the population of Nova Scotia is within 10 km of an ED and about 90% of the population is covered within 30 km of an ED. Most of the population is close to an ED as 99% of the population is covered within 60 km of an ED. This is a good indication of access to the EDs. There are thirteen DAs that are not served within 60 km of an ED however all the population is covered within 120 km.

Another metric of interest was measuring how many Emergency Departments are within 72 km of each Dissemination Area. The worst served DA in the current state using the p-median problem was 71.42 km from an ED thus 72 km was chosen to include the worst distance and to compare every other DA point to the current worst-served DA. The redundant coverage of DA points was measured using a 72 km Service Area for each ED. Table 4.7 displays the distribution for the number of EDs with 72 km of each DA.

Table 4.7 EDs within 72 km of a DA

EDs within 72 km	Population	% of Population	Number of DAs
0	0	0.00%	0
1	37,638	4.08%	69
2	54,627	5.93%	112
3	147,697	16.02%	291
4	229,580	24.91%	448
5	166,922	18.11%	273
6	260,134	28.22%	403
7	25,129	2.73%	34
Grand Total	**921,727**	**100.00%**	**1,630**

The entire population of NS is covered by at least one ED within 72 km. 96% of the population is covered by multiple EDs which indicates that most of the province is redundantly covered, meaning that if there is an ED closure they would be supported by another ED. About 87% of the population is within the three to six ED range which means they are well-covered.

4.4 ED to ED Analyses

The road distance from ED-to-ED was calculated in ArcGIS using the OD Cost Matrix tool in Network Analyst. This computes the distance by road from one point to another. It was particularly useful for calculating the distance from ED to ED and to determine how isolated an ED is. An OD Cost matrix determines and measures the least-cost paths along the network from multiple origins to multiple destinations [61]. In this instance, the origins and destinations are the ED facilities and the cost is distance in kilometres. A from-to chart such as the example seen in Table 4.8 was created using all 37 EDs as origins and again as destinations.

Table 4.8 From-To Chart Example

Distance from ED to ED (km)	Aberdeen Hospital	All Saints Springhill Hospital	Annapolis Community Health Centre	Buchanan Memorial Community Health Centre	Cape Breton Regional Hospital
Aberdeen Hospital	-	129.3	284.6	312.1	242.3
All Saints Springhill Hospital	129.3	-	304.9	440.2	370.4
Annapolis Community Health Centre	284.6	304.9	-	595.5	525.7
Buchanan Memorial Community Health Centre	312.1	440.2	595.5	-	160.4
Cape Breton Regional Hospital	242.3	370.4	525.7	160.4	-

This table could then be summarized in different ways to show information about different ED types. The maximum minimum distance was determined to see what the furthest distance from ED type to ED type is as seen in Table 4.9.

Table 4.9 ED-to-ED Maximum Minimum Distance (km)

		ED Level				
	Maximum Minimum Distance (km)	**Tertiary**	**Regional**	**Community**	**CEC**	**Any ED**
ED Level	**Tertiary**	-	391.3	461.0	408.1	461.0
	Regional		652.7	722.5	669.5	722.5
	Community			649.4	596.5	722.5
	CEC				542.6	669.5

The maximum minimum distance is used to show what the longest of the shortest path distances from one ED type to another is. The value of 391.25 km from a Regional ED to a Tertiary ED indicates that the furthest distance along the shortest path by road from a Regional ED to a Tertiary ED is 391.25 km. The any column indicates the longest shortest path distance from a specified ED type to an ED of any other type.

The minimum distance from ED type to ED type was also calculated and can be seen in Table 4.10. This represents the shortest distance from one ED type to the next.

Table 4.10 ED-to-ED Minimum Distance (km)

		ED Level				
	Minimum Distance (km)	**Tertiary**	**Regional**	**Community**	**CEC**	**Any ED**
ED Level	**Tertiary**	-	7.0	15.9	41.8	7.0
	Regional		-	15.9	20.1	7.0
	Community			-	17.5	15.9
	CEC				-	17.5

The average distance from ED type to ED type was also calculated and can be seen in Table 4.11.

Table 4.11 ED-to-ED Average Distance

		ED Level				
	Average Distance (km)	**Tertiary**	**Regional**	**Community**	**CEC**	**Any ED**
ED Level	**Tertiary**	-	170.9	242.1	170.4	202.7
	Regional		218.5	267.6	216.4	242.0
	Community			263.2	270.2	265.2
	CEC				183.7	235.7

4.5 Full-Service EDs

There are currently 29 full-service EDs (non-CEC Emergency Departments) in Nova Scotia. The system was reviewed using the p-median problem to determine which full-service ED(s) should be removed if 1,2,3,4, or 5 EDs were removed from the system. The DA to ED distance, DA to ED population weighted distance, number of EDs within 82 km of each DA, and ED population are shown in Table 4.12. The number of EDs within 82 km was shown as the worst served distance of the entire system is 81.08 km which was rounded up to 82 km to determine if any of the changes to the system would make this measure worse than the current state distance.

Table 4.12 Removing Full-Service EDs

	Number of Full-Service EDs	**29 (current)**	**28**	**27**	**26**	**25**	**24**
DA to ED Distance (km)	Average	14.38	14.46	14.54	14.64	14.79	14.97
	Maximum	81.08	81.08	81.08	81.08	81.08	81.08
	Total	23,447	23,576	23,703	23,861	24,104	24,407
DA to ED Pop-Weighted Distance	Average	7,882	7,919	7,963	8,017	8,093	8,181
	Maximum	55,605	55,605	55,605	55,605	55,605	55,605
	Total	12,847,076	12,907,997	12,979,632	13,067,164	13,191,669	13,334,962
Number of EDs within 82 km of each DA	Average	3.54	3.54	3.51	3.47	3.37	3.36
	Maximum	8	8	8	8	7	7
	Minimum	1	1	1	1	1	1
ED Population	Average	31,784	32,919	34,138	35,451	36,869	38,405
	Maximum	159,724	159,724	159,724	159,724	159,724	159,724
	Minimum	1,348	2,725	2,725	2,769	2,769	3,198

Removing EDs does not change the furthest distance from a DA to a full-service ED, and that it has minimal impact on the average DA to ED distance. The maximum population assigned to a full-service ED through the p-median problem also does not change as EDs are removed.

4.6 Benchmarking

This section explores benchmarking the NS system to the systems in NB and PEI. Benchmarking across other provinces was deemed an important way to add context to understanding the performance level of the Nova Scotia Emergency Care System. NB and PEI were chosen as benchmark provinces due to their proximity, similar populations (size and demographics) and their similarly large rural areas. There was also knowledge of the nuances of both systems. Other provinces were considered for comparison however due to lack of system knowledge they were not chosen for analyses. The data for NB and PEI is introduced in this chapter and then analyzed using the same methods previously explained in Chapter 3. The provinces were compared based on the measured distance and population-weighted distance of each system.

4.6.1 New Brunswick

The New Brunswick EDs are split between two heath networks: The Horizon Health Network (HHN) (English), and the Vitalité Health Network (VHN) (French). The names of the EDs and the type can be seen in Table 4.13. The Saint John Regional Hospital and St. Joseph’s Hospital are both located in Saint John and are close enough (5.4 km apart) that they have been consolidated for analyses. The Moncton Hospital is part of the Horizon Health Network and the Dr. Georges-L.-Dumont University Hospital Centre is part of the Vitalité Health Network however they are both located in Moncton (2.2 km apart) and therefore serve the same catchment population and have been consolidated for analyses.

Table 4.13 NB EDs

ED	ED Type	Town	Network
Charlotte County Hospital	Community	Saint Stephen	HHN
Dr. Everett Chalmers Regional Hospital	Regional	Fredericton	HHN
Grand Manan Hospital	Community	Grand Manan	HHN
Hotel-Dieu of St. Joseph	Community	Perth-Andover	HHN
Miramichi Regional Hospital	Regional	Miramichi	HHN
Oromocto Public Hospital	Community	Oromocto	HHN
Sackville Memorial Hospital	Community	Sackville	HHN
Saint John Regional Hospital / St. Joseph's Hospital	Tertiary	Saint John	HHN
Sussex Health Centre	Community	Sussex	HHN

ED	ED Type	Town	Network
The Moncton Hospital / Dr. Georges-L.-Dumont University Hospital Centre	Regional	Moncton	HHN / VHN
Upper River Valley Hospital	Community	Waterville	HHN
Stella-Maris-de-Kent Hospital	Community	Sainte-Anne-de-Kent	VHN
Enfant-Jésus RHSJ† Hospital	Community	Caraquet	VHN
Tracadie-Sheila Hospital	Community	Tracadie	VHN
Campbellton Regional Hospital	Regional	Campbellton	VHN
Hôtel-Dieu Saint-Joseph de Saint-Quentin	Community	Saint-Quentin	VHN
Edmundston Regional Hospital	Regional	Edmunston	VHN
Grand Falls General Hospital	Community	Grand Falls	VHN

The New Brunswick EDs can be seen in Figure 4.4.

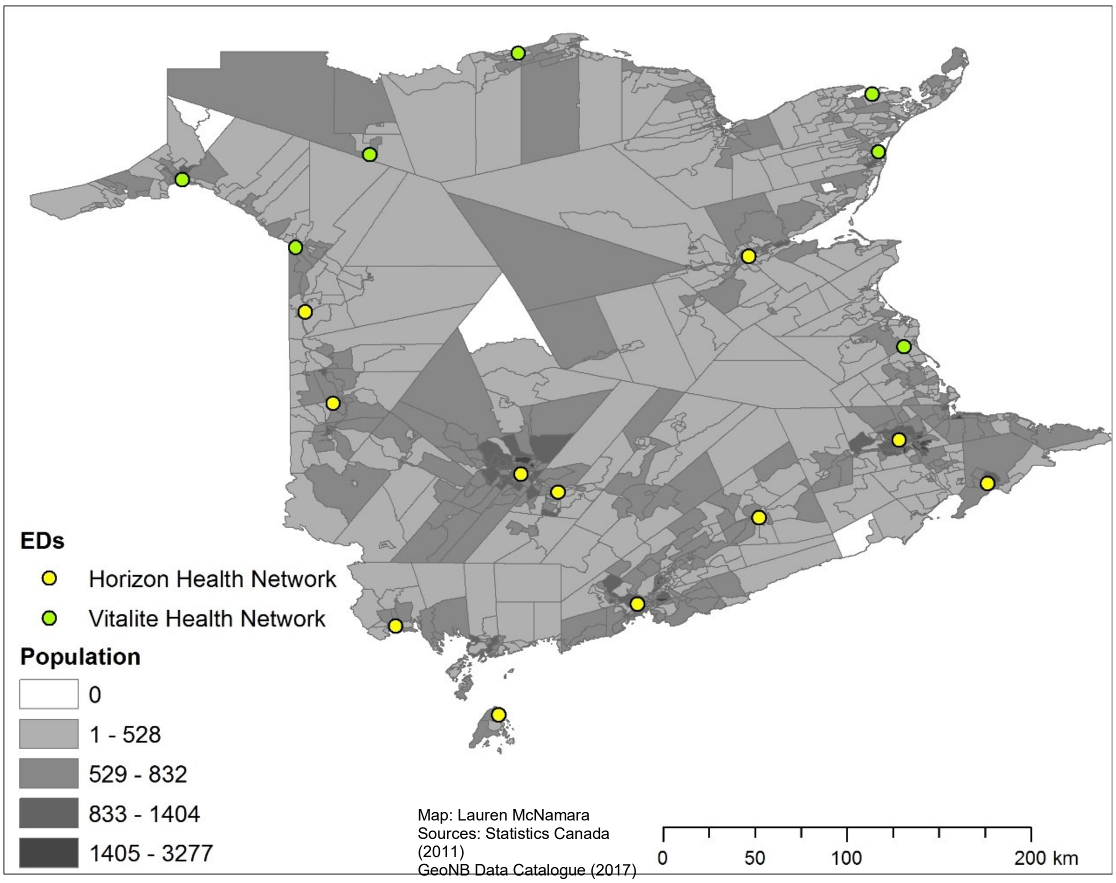

Figure 4.4 NB EDs

The NB road network from the GeoNB Data Catalogue was used for analyses [62].The New Brunswick population was assigned using the same method used in the analyses of Nova Scotia. The Statistics Canada Census Dissemination Areas were used and the centroid was calculated and then moved to the closest road.

The p-median problem was applied in the ArcGIS Network Analyst and the results can be seen in Table 4.14.

Table 4.14 NB P-median Results

ED	Population	% of Total Population	Sum of Distance (km)	Population-Weighted Distance
Campbellton Regional Hospital	32,007	4.26%	2,288.34	1,004,558.61
Charlotte County Hospital	22,326	2.97%	1,377.23	638,297.11
Dr. Everett Chalmers Regional Hospital	96,498	12.85%	2,313.67	1,376,001.01
Edmundston Regional Hospital	28,122	3.74%	870.96	373,631.49
Enfant-Jésus RHSJ† Hospital	52,566	7.00%	5,688.38	2,609,731.90
Grand Falls General Hospital	15,447	2.06%	385.73	178,083.86
Grand Manan Hospital	5,325	0.71%	336.30	151,169.22
Hotel-Dieu of St. Joseph	9,582	1.28%	370.22	174,822.25
Hôtel-Dieu Saint-Joseph de Saint-Quentin	8,321	1.11%	537.82	236,545.05
Miramichi Regional Hospital	40,551	5.40%	2,371.78	1,090,752.96
Oromocto Public Hospital	31,715	4.22%	1,679.63	769,168.55
Sackville Memorial Hospital	18,673	2.49%	780.11	404,758.17
Saint John Regional Hospital / St. Joseph's Hospital	124,760	16.61%	3,608.44	1,965,679.35
Stella-Maris-de-Kent Hospital	27,983	3.73%	1,520.87	686,084.05
Sussex Health Centre	27,194	3.62%	1,353.26	638,728.81
The Moncton Hospital / Dr. Georges-L.-Dumont University Hospital Centre	154,005	20.50%	2,776.94	1,740,916.74
Tracadie-Sheila Hospital	26,177	3.48%	1,119.88	492,856.58
Upper River Valley Hospital	29,919	3.98%	1,573.73	800,392.58
Grand Total	**751,171**	**100.00%**	**30,953.28**	**15,332,178.28**

The population-weighted distance for NB was also summarized in Table 4.15.

Table 4.15 NB Population-Weighted Distance

Population-Weighted Distance	Population	% of Total Population	Number of DAs
0-5,000	262,738	34.98%	559
5,000-10,000	149,279	19.87%	269
10,000-15,000	122,256	16.28%	214
15,000-20,000	80,686	10.74%	147
20,000-25,000	53,168	7.08%	93
25,000-30,000	29,532	3.93%	51
30,000-35,000	17,877	2.38%	35
35,000-40,000	13,970	1.86%	19
40,000-45,000	11,075	1.47%	20
45,000-50,000	5,800	0.77%	7
50,000-55,000	1,201	0.16%	2
55,000-60,000	1,328	0.18%	2
60,000-65,000	770	0.10%	1
115,000-120,000	1,491	0.20%	1
Grand Total	**751,171**	**100.00%**	**1,420**

It can be seen from this table that 34.98% of the population in New Brunswick have a population-weighted distance between 0 and 5,000 population-weighted km. This is slightly lower than Nova Scotia, where 48.63% of the population fits within the same range. The highest range for Nova Scotia is 55,000-60,000 population weighted km which is about half of the highest range in New Brunswick.

4.6.2 Prince Edward Island

PEI has four EDs with varying levels of service as seen in Table 4.16

Table 4.16 PEI EDs

ED	Town	Type
Queen Elizabeth Hospital	Charlottetown	Tertiary/Regional (depending on speciality service area)
Prince County Hospital	Summerside	Regional
Kings County Memorial Hospital	Montague	Community (8:00 AM – 10:00 PM)
Western Hospital	Alberton	Community (8:00 AM – 8:00 PM) CEC (8:00 PM – 8:00 AM)

The PEI EDs can be seen in Figure 4.5.

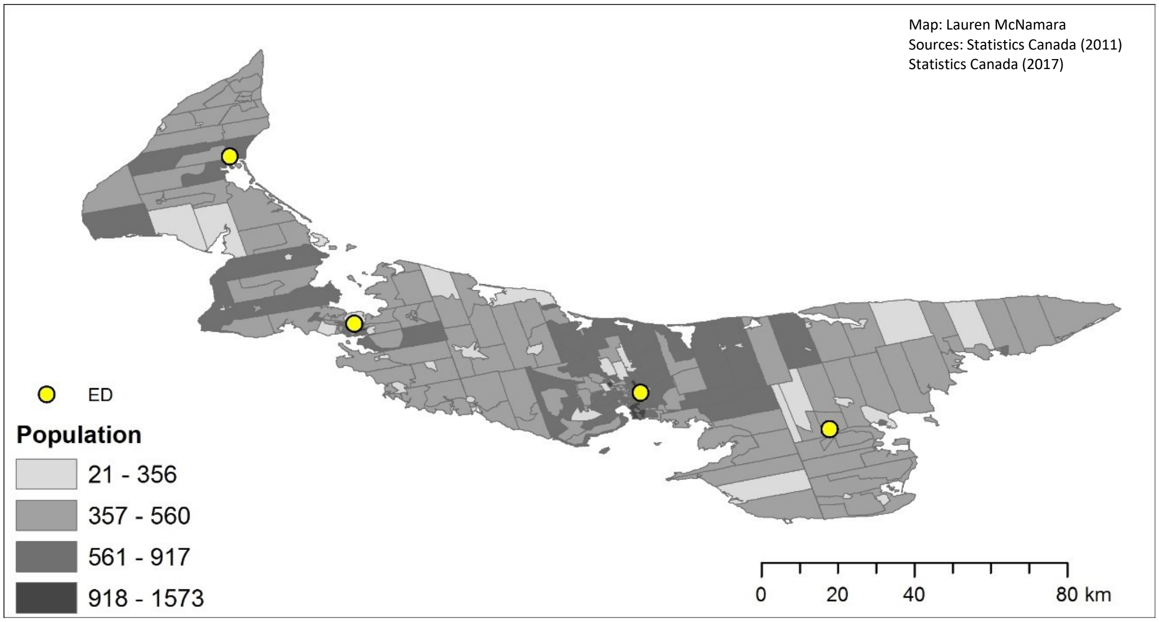

Figure 4.5 PEI EDs

The PEI road network from the Statistics Intercensal Road Network files were used in ArcGIS [63]

The population was used in the same way as the NS analyses by calculating the geographic centroid of Statistics Canada Census Dissemination Areas and moving the point to the closest road network,

The p-median location-allocation problem was applied in ArcGIS and the results can be seen in Table 4.17.

Table 4.17 PEI P-median Results

ED	Population	% of Total Population	Sum of Distance (km)	Population-Weighted Distance
Queen Elizabeth Hospital	71,660	51.11%	1,449.72	727,967.54
Prince County Hospital	34,323	24.48%	1,069.90	460,481.87
Kings County Memorial Hospital	21,287	15.18%	1,150.43	482,873.61
Western Hospital	12,934	9.23%	509.34	218,711.32
Grand Total	**140,204**	**100.00%**	**4,179.40**	**1,890,034.35**

The population-weighted distance was summarized in Table 4.18.

Table 4.18 PEI Population-Weighted Distance

Population-Weighted Distance	Population	% of Total Population	Number of DAs
0-5,000	62,429	44.53%	139
5,000-10,000	39,914	28.47%	80
10,000-15,000	27,647	19.72%	53
15,000-20,000	7,362	5.25%	14
20,000-25,000	1,655	1.18%	3
30,000-35,000	1,197	0.85%	2
Grand Total	**140,204**	**100.00%**	**291**

PEI has 44.53% of the population within the range of 0-5,000 population-weighted km. This is slightly lower but still close to NS, where 48.63% of the population fits within the same range. The highest range for Nova Scotia is 55,000-60,000 population which exceeds the 30,000-35,000 population-weighted km range maximum in PEI.

4.6.3 Comparison

NS has a population of 921,727 and 37 EDs, NB has a population of 751,171 and 18 EDs, and PEI has a population of 140,204 and four EDs. The compared p-median results for the three Maritime provinces can be seen in Table 4.19.

Table 4.19 Benchmarking

					DA to ED					
					Distance (km)			Population-Weighted Distance		
	Pop	EDs	km^2	Pop/ km^2	Avg	Max	Total	Avg	Max	Total
NS	921,727	37	55K	16.7	**12.8**	71.4	21K	7,062	55.6K	11.5M
NB	757,171	18	73K	10.4	21.8	102.3	31K	10,797	117.6K	15.3M
PEI	140,204	4	5.6K	25.0	14.4	**62.4**	**4K**	**6,495**	**31.9K**	**1.9M**

Based on the p-median problem, NS has a total population-weighted distance of 11,511,037; NB has a total population-weighted distance of 15,332,178; and PEI has a total population-weighted distance of 1,890,034. NB has a smaller population that NS however the population-weighted distance is higher meaning that more people are travelling a further distance to reach EDs in NB.

Chapter 5 Greenfield Analyses

This chapter applies greenfield analyses to the system. A greenfield analysis involves running a model using the assumption that there is no existing system. This means optimizing the system based on the demand without any EDs located in the system. Several greenfield analyses were performed to determine where the EDs should go based on population and distance metrics. The locations of the DA points were used as candidates for ED facilities, and the DA points were used as the demand points and were weighted by their population. First, a model of the system with its EDs relocated to satisfy the p-median problem objective is explored. Next, a model incorporating the minimization of the number of ED facilities while maximizing the population coverage is investigated. Finally, a model adding EDs to the system which forces the distance from the population to the EDs to be less than the current average distance is described.

5.1.1 Relocate existing EDs

A green field analysis was performed to determine where the current 37 EDs should be located based on distance and population. This analysis used the minimum travel distance weighted by population density (p-median problem) and relocated the EDs as seen in Figure 5.1.

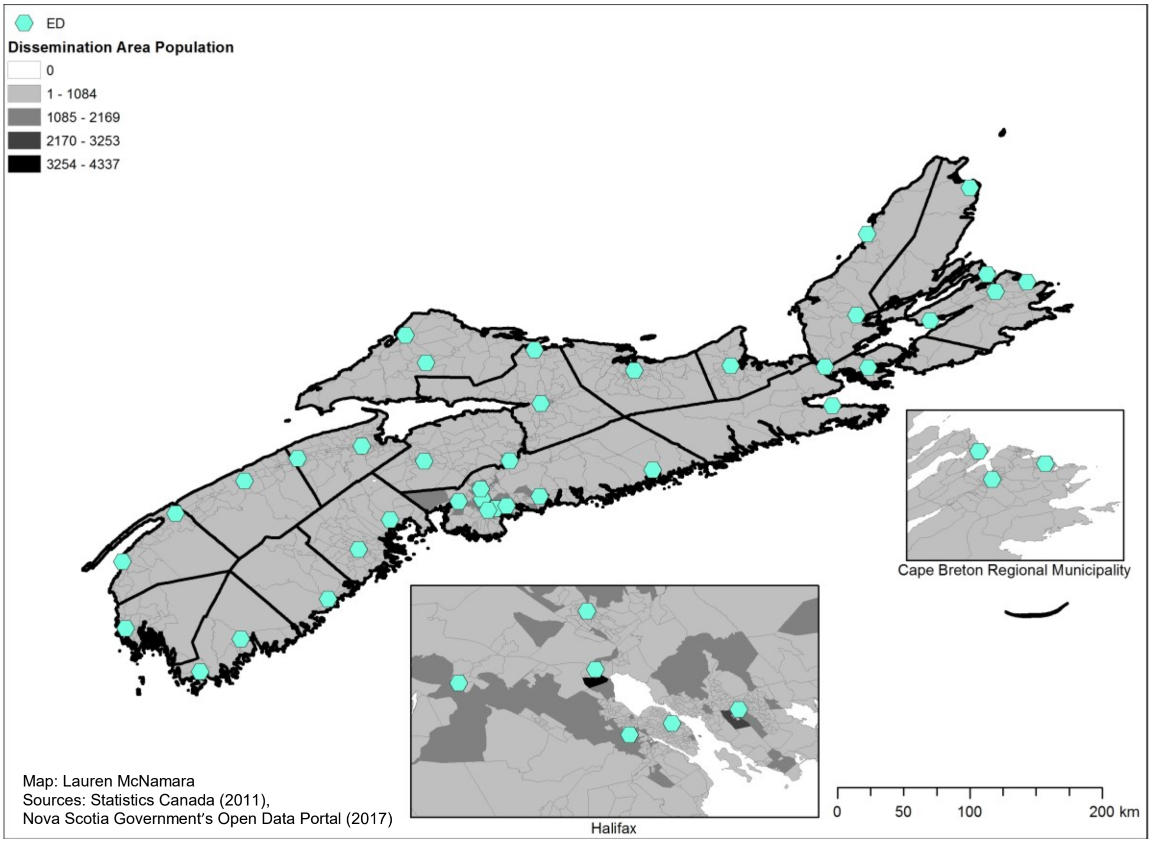

Figure 5.1 Relocate existing EDs

This model is interesting as most of the EDs in the new model are located close to where the existing EDs are. In the Cape Breton Regional Municipality where the existing EDs were clustered in a group of four the number has been reduced to three, whereas the Halifax area had three EDs in the existing system and the new model has increased this to six.

5.1.2 Minimize facilities/maximize coverage

A second greenfield analysis was performed to determine how many EDs are needed based on distance and population such that no distance from a DA to an ED exceeds the current longest distance of 71.42 km. The LSCP model was applied using the ArcGIS Network Analyst location-allocation tool, using the minimize facilities/maximize coverage option. This resulted in 15 EDs located as seen in Figure 5.2. The model does not account for facility capacity or facility type.

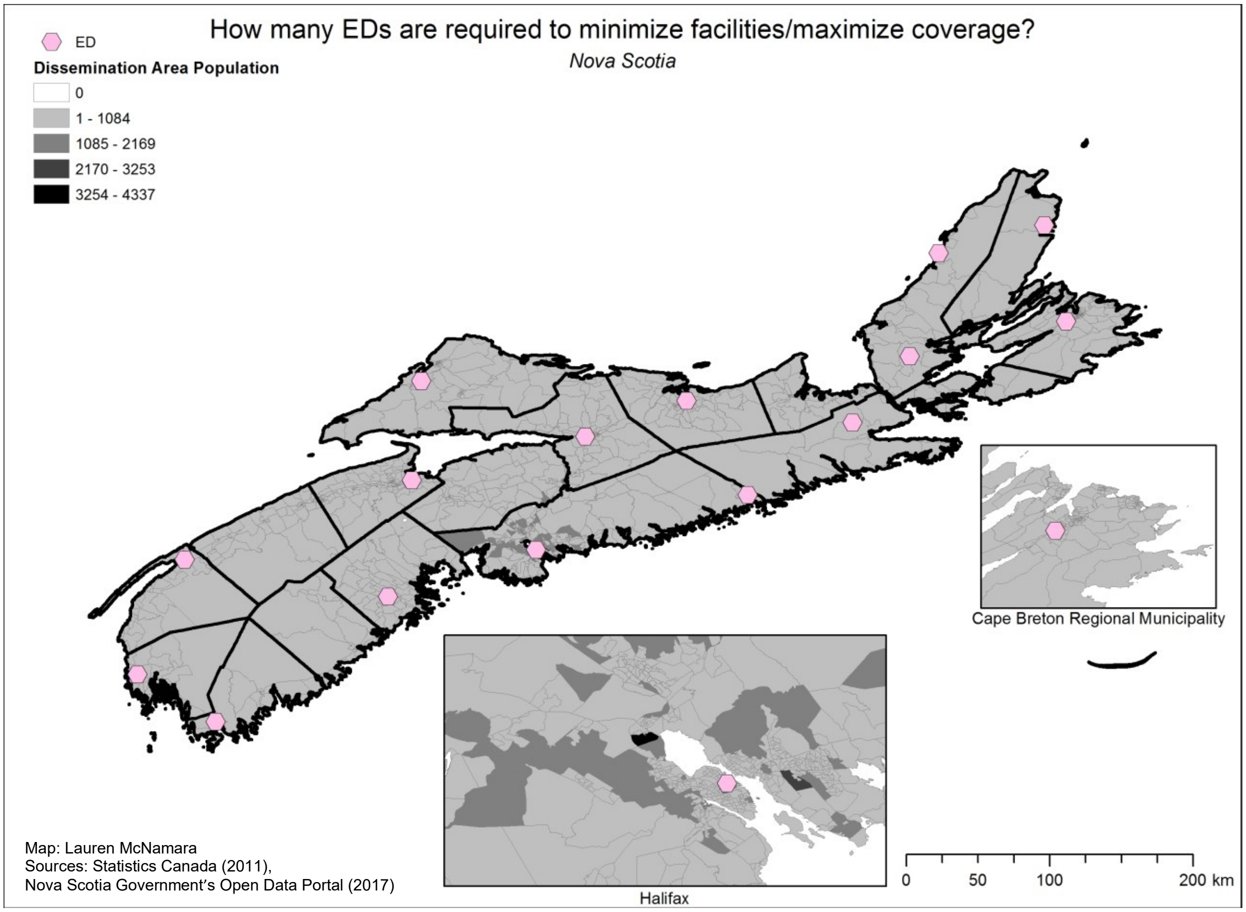

Figure 5.2 Minimize facilities/maximize coverage

This model has EDs close to where the existing EDs are, however in areas such as Halifax and the Cape Breton Regional Municipality where there were clusters of EDs in the existing system, these clusters have been reduced to one ED.

5.1.3 Current Average Distance

A third greenfield analysis calculated how many EDs are needed such that no DA to ED distance is further than the current average distance of 12.8 km. This was modeled using the LSCP and results in an equality solution of 270 EDs and can be seen in Figure 5.3.

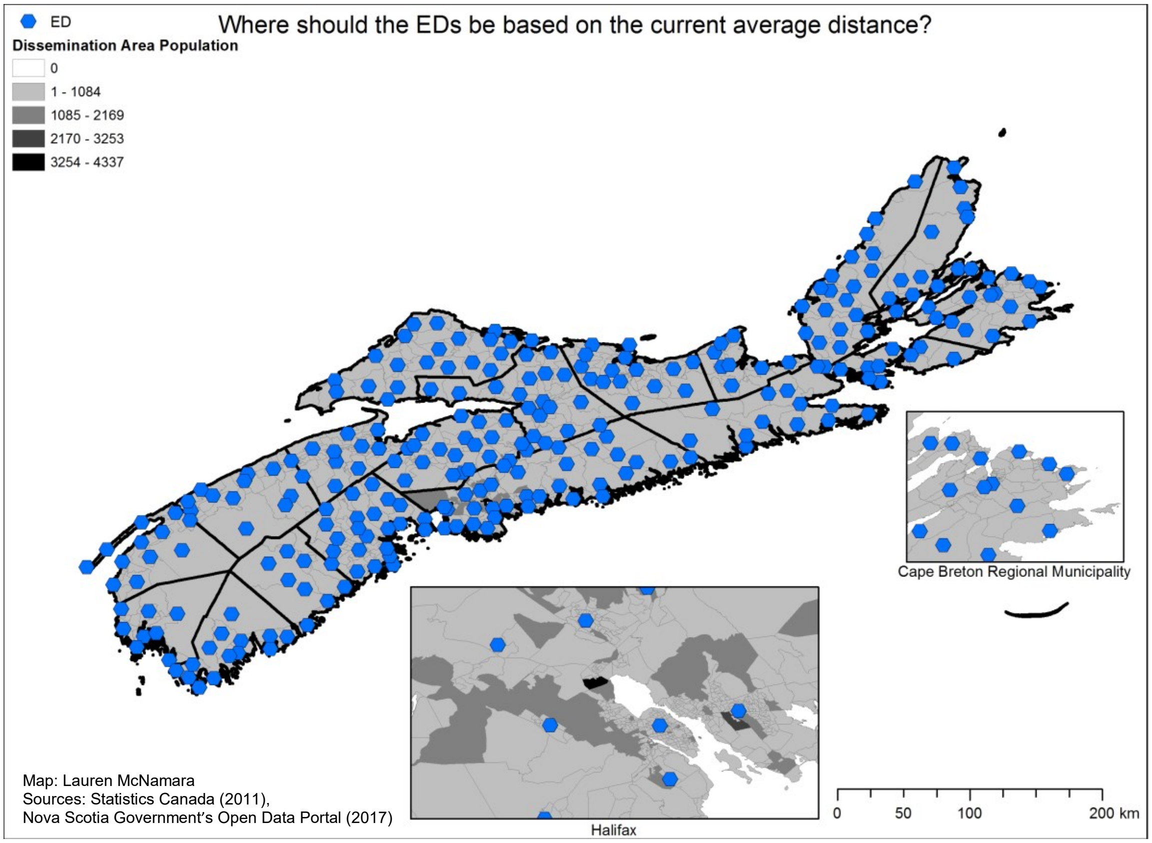

Figure 5.3 Current Average Distance

This model is interesting as it strives for an equality solution. In practice, the model would be unsustainable as the costs of opening and running 270 EDs would be high, and the number of necessary resources to run the EDs would also be significant.

Chapter 6 CEC Analyses

This chapter focuses specifically on the analyses of CECs within the NS Emergency Care system. The possible CECs identified in the Ross Report are compared to the existing CEC sites. The CTAS arrivals at each site are presented, followed by the measurement of distances from the CECs to tertiary, regional, and community EDs. The local effects of changing the possible sites to a CEC are explored, and St. Mary's Memorial Hospital is used as a case study. The system effects are also measured for removing a CEC, selecting which full-service EDs could become CECs based on the p-median model, and changing the full-service EDs to CECs.

6.1 Current and Possible CECs

The Ross Report identified 14 sites for possible CEC implementation which are shown Table 6.1 [4]. There are currently 8 CECs in operation and 6 other sites that were identified as possible locations for new CECs.

Table 6.1 CECs [4]

ED	Current CEC	Possible CEC
All Saints Springhill Hospital	X	
Annapolis Community Health Centre	X	
Eastern Memorial Hospital		X
Fisherman's Memorial		X
Lillian Fraser Hospital	X	
Musquodoboit Valley Memorial Hospital	X	
New Waterford Consolidated Hospital	X	
North Cumberland Memorial Hospital	X	
Northside General Hospital		X
South Cumberland Community Care Centre	X	
St. Anne's Community and Nursing		X
St. Mary's Memorial Hospital		X
Twin Oaks Hospital	X	
Victoria County Memorial Hospital		X

The locations can be seen on a map of Nova Scotia in Figure 6.1.

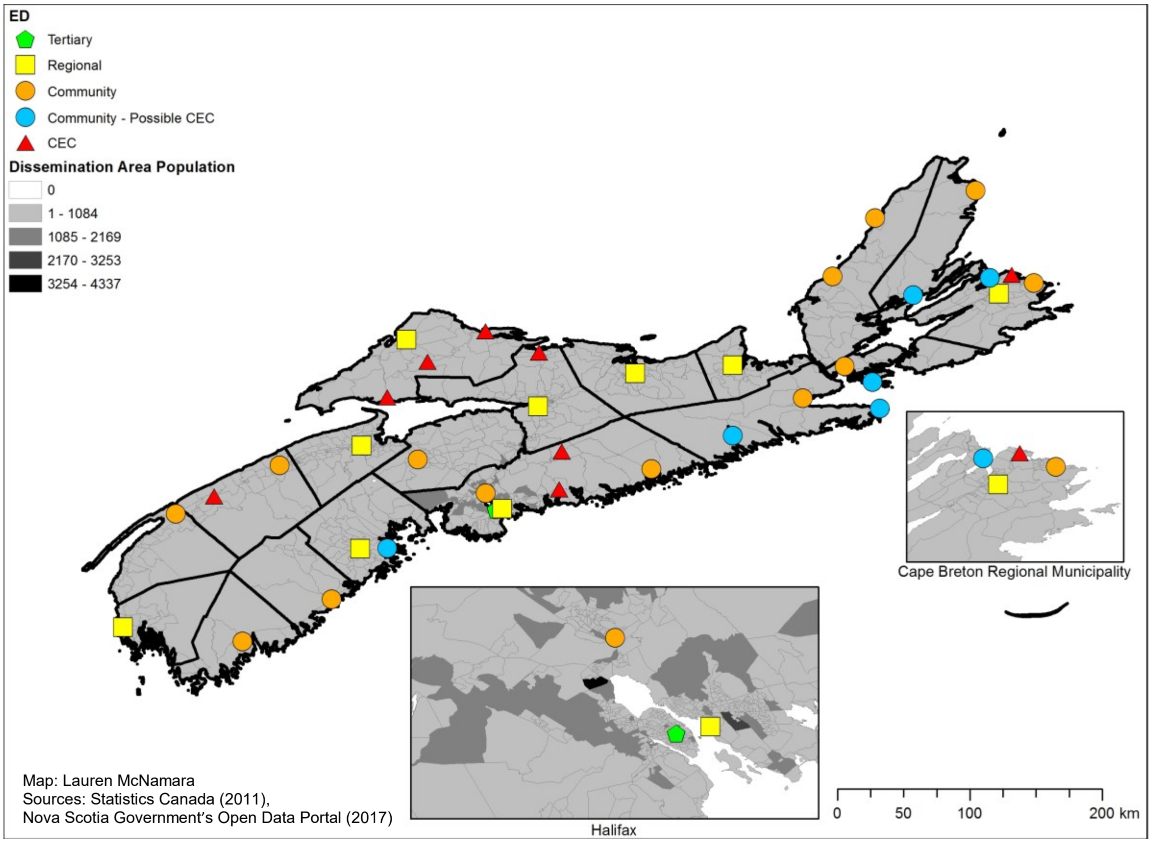

Figure 6.1 Possible CECs

6.2 CTAS

The Canadian Triage and Acuity Scale (CTAS) levels for the current CECs and the possible new CECs from 2008-2010 were identified in the Ross Report and can be seen in Table 6.2. The levels are defined as the following [64]:

- CTAS 1: life- or limb-threatening
- CTAS 2: severe pain or unstable vital signs
- CTAS 3: moderate illness that may require some tests
- CTAS 4: possible bone fracture or large cuts
- CTAS 5: minor injury.

Table 6.2 CEC CTAS from 2008-2010 [4]

ED	Status	CTAS 1	CTAS 2	CTAS 3	CTAS 4	CTAS 5
All Saints Springhill Hospital	CEC	0.2%	2.5%	16.0%	50.0%	30.0%
Annapolis Community Health Centre	CEC	0.1%	1.1%	10.4%	32.5%	54.0%
Eastern Memorial Hospital	Possible CEC	0.1%	0.7%	8.5%	50.0%	38.0%
Fishermen's Memorial Hospital	Possible CEC	0.0%	1.6%	20.7%	66.4%	11.3%
Lillian Fraser Memorial Hospital	CEC	0.1%	2.0%	20.0%	46.3%	18.3%
Musquodoboit Valley Memorial Hospital	CEC					
New Waterford Consolidated Hospital	CEC	0.1%	1.0%	11.7%	74.7%	11.0%
North Cumberland Memorial Hospital	CEC	0.0%	0.4%	5.0%	33.0%	58.0%
Northside General Hospital	Possible CEC	0.2%	3.0%	22.0%	57.0%	17.0%
South Cumberland Community Care Centre	CEC	0.1%	1.0%	6.0%	34.0%	57.0%
St. Anne's Community and Nursing	Possible CEC				89%	
St. Mary's Memorial Hospital	Possible CEC	0.5%	0.7%	7.8%	41.0%	49.0%
Twin Oaks Memorial Hospital	CEC					
Victoria County Memorial Hospital	Possible CEC	0.2%	1.5%	13.0%	47.0%	26.0%

The CECs and possible CECs predominantly treat CTAS 3 to CTAS 5 patients for moderate to minor injuries. There is a low frequency of higher acuity CTAS 1 and CTAS 2 patients presenting at the CECs and possible CECs.

6.3 Distance

The minimum distance from each current CEC to a tertiary, regional, or community ED was calculated, as well as defining the minimum distance from a CEC to any higher-level ED. These results can be seen in Table 6.3.

Table 6.3 CEC to other ED distance

ED	Distance to closest ED (km)			
	Tertiary ED	Regional ED	Community ED	Closest ED
All Saints Springhill Hospital	174.3	22.5	161.6	22.5
Annapolis Community Health Centre	185.4	**95.5**	32.6	32.6
Lillian Fraser Memorial Hospital	136.0	45.9	123.4	45.9
Musquodoboit Valley Memorial Hospital	71.3	46.0	58.6	46.0
New Waterford Consolidated Hospital	**408.1**	**20.1**	**17.5**	**17.5**
North Cumberland Memorial Hospital	166.3	49.2	153.6	49.2
South Cumberland Community Care Centre	180.2	51.8	**167.5**	**51.8**
Twin Oaks Memorial Hospital	**41.8**	38.3	49.5	38.3

Column Min, **Column Max**

In the current model, New Waterford Consolidated Hospital is the least isolated CEC as it is 17.5 km from the closest ED. South Cumberland Community Care Centre is the most isolated at 51.8 km away from the closest ED.

6.4 Local Effects

6.4.1 Change St. Mary's Memorial Hospital to a CEC

St. Mary's Memorial Hospital is one of the community EDs that has been identified as a possible CEC site. This site was considered as a case study to explore and help illustrate the metrics of importance. The distance from St. Mary's to other EDs was identified in Table 6.4.

Table 6.4 Distance from St. Mary's to Other EDs

ED	ED Level	Distance (km)
St. Martha's Regional Hospital	Regional	63.7
Guysborough Memorial Hospital	Community	71.3
QEII – Halifax Infirmary Site	Tertiary	190.4

St. Mary's was then compared to the existing CECs to determine it compared in terms of isolation, catchment population, furthest DA, and population weighted distance as seen in Table 6.5.

Table 6.5 St. Mary's compared to existing CECs

ED	Closest ED (km)	Catchment Population	Furthest DA (km)	Population-Weighted Distance
New Waterford Consolidated Hospital	**17.5**	10,484	**9.4**	**29,791**
All Saints Springhill Hospital	22.5	7,643	25.5	66,982
Annapolis Community Health Centre	32.6	6,454	34.5	97,689
Twin Oaks Memorial Hospital	38.3	**13,457**	30.0	219,536
Lillian Fraser Memorial Hospital	45.9	6,293	35.1	121,097
Musquodoboit Valley Memorial Hospital	46.0	12,991	38.5	**338,539**
North Cumberland Memorial Hospital	49.2	4,697	35.9	86,645
South Cumberland Community Care Centre	51.8	4,095	**47.7**	95,473
St. Mary's Memorial Hospital	**63.7**	**2,725**	**47.5**	78,904

Column Min, **Column Max**

St. Mary's is more isolated from other EDs compared to the existing CECs. It also has the lowest population. It ties with South Cumberland Community Care Centre for the longest DA travel distance, and fits in the middle for population-weighted distance. The isolation and population metrics were also plotted in Figure 6.2 to depict whether St. Mary's was comparable.

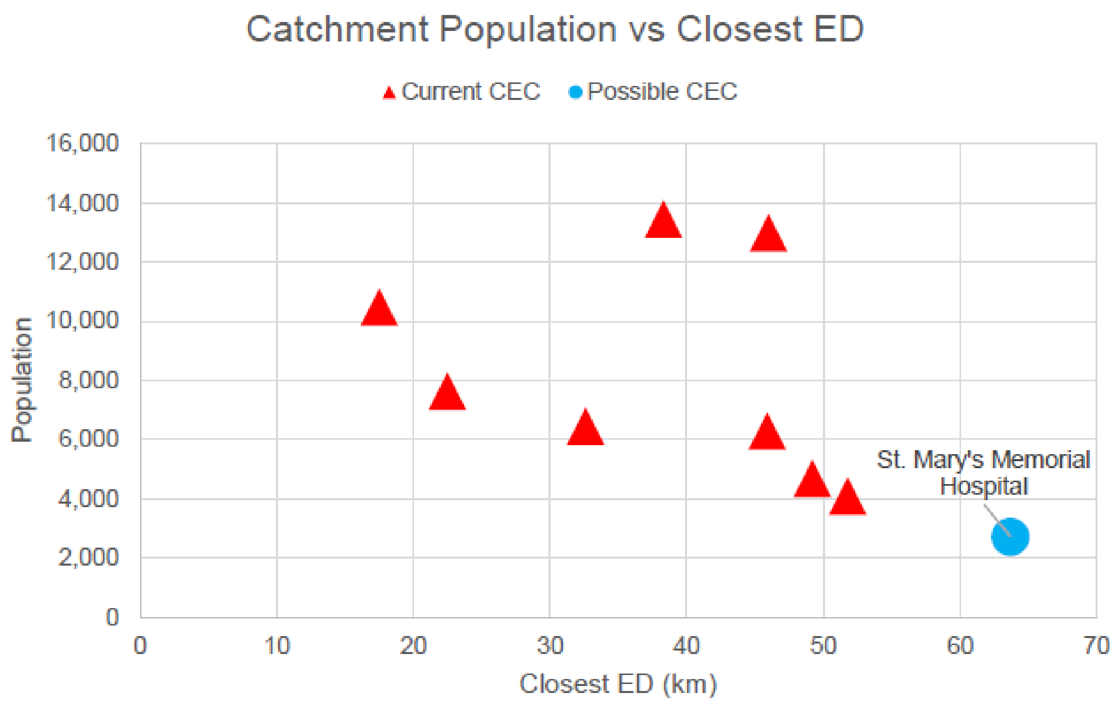

Figure 6.2 St. Mary's compared to existing CEC Population and Isolation

St. Mary's would redefine both the population and isolation metrics if it was to become a CEC, as it is more isolated and has a smaller population than the existing CECs.

6.4.2 Other Possible CECs

The same method that was used for St. Mary's Memorial Hospital was applied to the other possible CECs and the results can be seen in Table 6.6.

Table 6.6 Possible CECs

CEC Status	ED	Closest ED (km)	Catchment Population	Furthest DA (km)	Population-Weighted Distance
C	New Waterford Consolidated Hospital	**17.5**	10,484	**9.4**	29,791
P	Fishermen's Memorial Hospital	18.4	18,072	60.9	**390,170**
C	All Saints Springhill Hospital	22.5	7,643	25.5	66,982
P	Northside General Hospital	24.2	**21,342**	**65.8**	196,761
P	St. Anne's Community and Nursing	27.6	3,286	10.5	26,259

CEC Status	ED	Closest ED (km)	Catchment Population	Furthest DA (km)	Population-Weighted Distance
C	Annapolis Community Health Centre	32.6	6,454	34.5	97,689
C	Twin Oaks Memorial Hospital	38.3	13,457	30.0	219,536
C	Lillian Fraser Memorial Hospital	45.9	6,293	35.1	121,097
C	Musquodoboit Valley Memorial Hospital	46.0	12,991	38.5	338,539
C	North Cumberland Memorial Hospital	49.2	4,697	35.9	86,645
P	Eastern Memorial Hospital	50.3	**1,348**	13.2	**5,646**
C	South Cumberland Community Care Centre	51.8	4,095	47.7	95,473
P	Victoria County Memorial Hospital	58.0	3,584	41.2	63,403
P	St. Mary's Memorial Hospital	**63.7**	2,725	47.5	78,904

C=Current CEC, P=Possible CEC

St. Mary’s is again the most isolated while Eastern Memorial Hospital has the lowest catchment population. Northside General has the furthest DA which indicates that it has the largest geographic coverage. Fisherman’s Memorial Hospital has the largest population-weighted distance.

Population and isolation are again two of the most important metrics and they were plotted in Figure 6.3 to see how the current and the possible CECs compare.

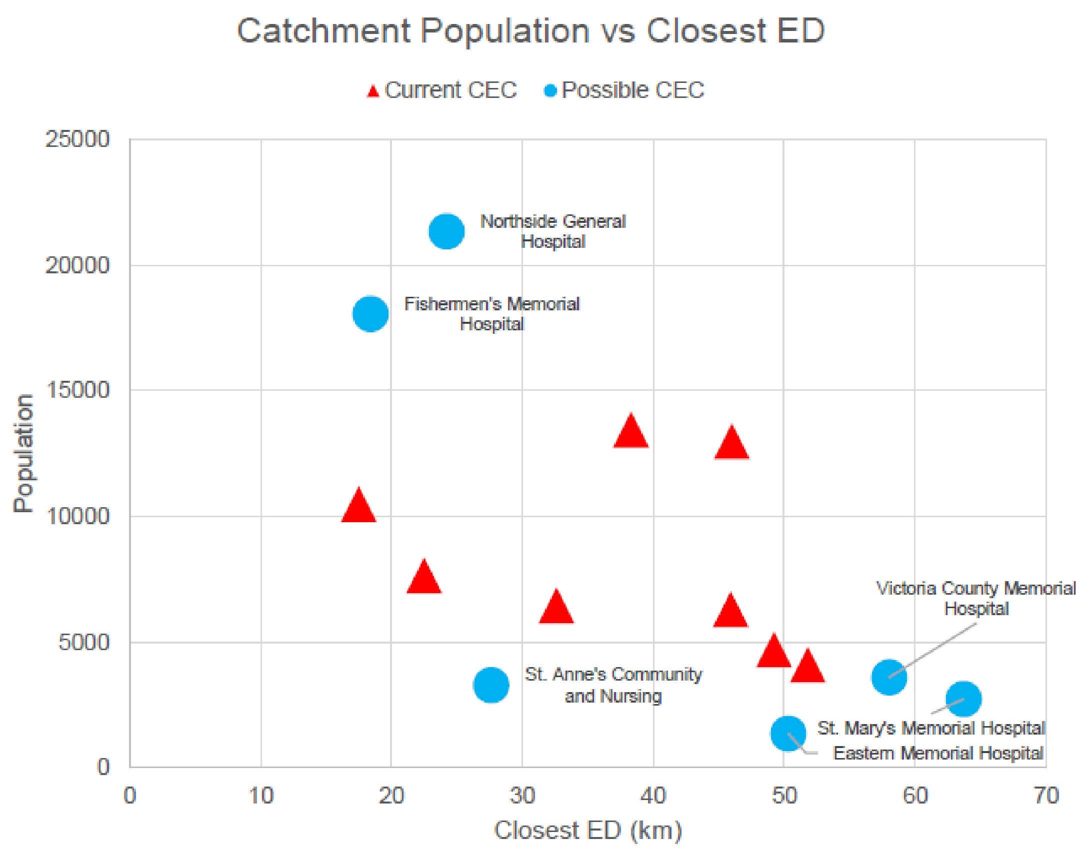

Figure 6.3 Current and Possible CEC Catchment Population vs Isolation

St. Mary's Memorial Hospital and Victoria County Memorial Hospital fit within the population of the current CECs however they are both more isolated. CECs need to be close to other system supports as they do not necessarily have the same access to supports such as Diagnostic Imaging or laboratory, particularly at night. In contrast, Fisherman's Memorial Hospital and Northside General Hospital are both located close to other EDs but have a much higher population than the existing range. It has been shown in other studies [28] that CECs have a diminished return when used with higher populations. St. Anne's Community and Eastern Memorial Hospital have similar isolation and population characteristics as the existing CECs.

6.5 System Effects

6.5.1 Remove a CEC

A model was run to determine which CEC would be removed from the system based on population and distance. The inputs included all 37 existing EDs with the tertiary, regional, and community sites as required facilities, and the eight CECs as candidate sites. The p-median problem was modelled using p = 36 or requiring 29 EDs and 7 CECs in the solution. The results indicate that North Cumberland Memorial Hospital is the CEC site that would be removed based on the minimum travel distance weighted by population density.

6.5.2 Changing Full-Service EDs to CECs

The system effects of changing each of the possible CECs from a Community ED to a CEC were also measured. The impact on the distance from a DA to a full-service ED, the population of the EDs, and the coverage of DAs by EDs within 82 km can be seen in Table 6.7. The number of EDs within 82 km was chosen because the worst -served DA to ED distance of the current state is 81.08 km which was rounded up to 82 km. This metric was chosen to see if the coverage changes as the possible CECs are changed to CECs.

Table 6.7 Changing Full-Service EDs to CECs

	Number of Full-Service EDs	**29 (current)**	**28**	**28**	**28**	**28**	**28**	**28**
	New CEC	N/A	Eastern Memorial	Fisherman's Memorial	Northside General	St. Anne's Community and Nursing	St. Mary's Memorial Hospital	Victoria County Memorial Hospital
DA to ED Distance (km)	Average	14.38	14.46	14.53	14.82	14.46	14.48	14.60
	Maximum	81.08	81.08	81.08	81.07	81.08	81.08	81.08
	Total	23,447	23,576	23,690	24,162	23,574	23,605	23,791
DA to ED Pop-Weighted Distance	Average	7,882	7,919	7,958	8,124	7,926	7,935	7,976
	Maximum	55,605	55,605	55,605	55,605	55,605	55,605	55,605
	Total	12,847,076	12,907,997	12,971,580	13,242,548	12,918,710	12,934,607	13,000,861
Number of EDs within 82 km of each DA	Average	3.54	3.54	3.44	3.42	3.51	3.51	3.46
	Maximum	8	8	7	8	8	8	8
	Minimum	1	1	1	1	1	1	1
ED Population	Average	31,784	32,919	32,919	32,919	32,919	32,919	32,919
	Maximum	159,724	159,724	159,724	159,724	159,724	159,724	159,724
	Minimum	1,348	2,725	1,348	1,348	1,348	1,348	1,348

It can be seen from the table that if any of the possible CECs are no longer a full-service it does not impact the maximum distance from a DA to a full-service ED, and that it has minimal impact on the average DA to ED distance. The maximum population assigned to a full-service ED through the p-median problem also does not change as EDs are removed.

Chapter 7 Tool

This chapter introduces the tool that was developed for stakeholders. It shows the development of the tool as well as the capabilities and functionality of the tool. The interface as well as how to evaluate the current state are shown first, followed by an explanation of the different changes that can be made to the current state.

7.1 Development

A key aspect of this research was to provide a tool that stakeholders could use to measure proposed changes to the system.

The first version of this tool was a database that allowed users to query the distance from a DA to an ED, or from an ED to another ED. It also provided the option to query the population-weighted distance from a DA to an ED. Reports summarizing minimums, maximums, averages, and sums could also be generated. This tool was not sophisticated enough to allow the user to investigate changes to the system.

The next version of the tool allowed the user to turn the existing EDs on and off which in turn causes the metrics such as the ED population, ED and DA population-weighted distances, and DA to ED distances to re-calculate. This tool allows the user to change what they think is interesting and provides a dashboard to summarize the results of changing an ED from open to closed. This tool also allows the user to choose a service distance, *S*, and determine how many DAs or what amount of the population is covered by at least one ED within that distance. The dashboard will also summarize the minimum, maximum, and mean for this metric.

This tool is important as it provides a way for planners to test changes to the system and see how those changes will impact the population throughout the province. It will also allow the user to investigate adding or removing EDs and the overall impact on the system.

7.2 Interface

The interface shows the user the name of the ED along with ED specific information. The user inputs include the zone (Central / Eastern / Northern / Western), the ED Type (CEC / Community / Regional / Tertiary / Undetermined), whether the ED is open (yes / no), and whether the ED is open at night (yes / no). There is also an area for the user to adjust the service distance *S*. A portion of the interface can be seen in Figure 7.1

ED	Zone	ED Type	ED Open	ED Open (Night)
Cobequid Community Health Centre	Central	Community	Yes	No
Colchester East Hants Health Centre	Northern	Regional	Yes	Yes
Cumberland Regional Health Care Centre	Northern	Regional	Yes	Yes
Dartmouth General Hospital	Central	Regional	Yes	Yes
Digby General Hospital	Western	Community	Yes	Yes
Eastern Memorial Hospital	Eastern	Community	Yes	Yes
Eastern Shore Memorial Hospital	Central	Community	Yes	Yes
Fishermen's Memorial Hospital	Western	Community	Yes	No

Figure 7.1 Interface

7.3 Evaluate Current State

The current state can be evaluated using several different metrics. Each ED is assigned a catchment population using the p-median problem with the objective of minimizing the population-weighted distance of the entire system. The catchment population for each ED is displayed in the main table as seen in Figure 7.2.

ED	Zone	ED Type	ED Open	ED Open (Night)	ED Catchment Population
Cobequid Community Health Centre	Central	Community	Yes	No	115,297
Colchester East Hants Health Centre	Northern	Regional	Yes	Yes	44,768
Cumberland Regional Health Care Centre	Northern	Regional	Yes	Yes	15,443
Dartmouth General Hospital	Central	Regional	Yes	Yes	108,035
Digby General Hospital	Western	Community	Yes	Yes	15,089
Eastern Memorial Hospital	Eastern	Community	Yes	Yes	1,348
Eastern Shore Memorial Hospital	Central	Community	Yes	Yes	2,579
Fishermen's Memorial Hospital	Western	Community	Yes	No	18,072

Figure 7.2 ED Catchment Population

This population will adjust as EDs are changed from open to closed.

Another display shows the closest ED to the named ED. This area of the tool will show the overall closest ED, as well as indicating the closest Tertiary ED, Regional ED, Community ED, or CEC and the corresponding distance in kilometres.

ED	Zone	ED Type	ED Open	ED Open (Night)	ED Catchment Population	Closest ED	Distance to Closest ED (km)
Aberdeen Hospital	Northern	Regional	Yes	Yes	43,355	St. Martha's Regional Hospital	57.84
All Saints Springhill Hospital	Northern	CEC	Yes	Yes	7,643	Cumberland Regional Health Care Centre	22.49
Annapolis Community Health Centre	Western	CEC	Yes	Yes	6,454	Digby General Hospital	32.64
Buchanan Memorial Community Health Centre	Eastern	Community	Yes	Yes	2,769	Sacred Heart Community Health Centre	89.78

Figure 7.3 Closest ED

The distance per ED can also be seen at the top of the tool. The *Average DA to ED Distance (km)* gives the average distance from a dissemination area point to the given Emergency Department. The minimum and maximum distance per ED are also given. The *Distance (km)* field gives the sum of the DA to ED distances for that specified ED. For example, the 992.1 km shown in the top row shows that the total distance travelled from all the DAs assigned to that ED is 992.1 km.

The population-weighted distance per ED can be seen at the top of the tool in population-weighted kilometres as seen in Figure 7.4. The *Average Assigned Population-Weighted Distance (km)* gives the average population-weighted distance from a dissemination area point to the given Emergency Department. The minimum and maximum population-weighted distance per ED are also given. The *ED Population-Weighted Distance (km)* field gives the sum of the DA to ED population-weighted distances for that specified ED. For example, the 476,616.96 shown in the top row shows that the sum of the population-weighted distance for each of the DAs assigned to that ED sum to 476,616.96 population-weighted km.

ED	Zone	ED Type	ED Open	ED Open (Night)	ED Catchment Population	Avg DA to ED Distance (km)	Min DA to ED Distance (km)	Max DA to ED Distance (km)	Distance (km)	Avg Assigned ED Population-Weighted Distance	Min Assigned ED Population-Weighted Distance	Max Assigned ED Population-Weighted Distance	ED Population-Weighted Distance
Aberdeen Hospital	Northern	Regional	Yes	Yes	43,355	11.1	0.4	39.4	992.1	5,355	240.22	24,465.85	476,616.96
All Saints Springhill Hospital	Northern	CEC	Yes	Yes	7,643	9.0	0.3	25.5	161.6	3,721	128.89	10,045.37	66,981.59
Annapolis Community Health Centre	Western	CEC	Yes	Yes	6,454	15.1	0.9	34.5	211.3	6,978	446.95	14,811.31	97,688.68
Buchanan Memorial Community Health Centre	Eastern	Community	Yes	Yes	2,769	28.6	3.9	71.4	171.7	13,968	1,739.60	40,139.00	83,808.35
Cape Breton Regional Hospital	Eastern	Regional	Yes	Yes	50,214	11.6	0.8	67.5	1,133.2	6,117	206.44	36,405.14	599,438.29
Cobequid Community Health Centre	Central	Community	Yes	No	115,297	13.7	0.0	48.3	2,102.7	10,537	13.05	55,176.20	1,612,195.23
Colchester East Hants Health Centre	Northern	Regional	Yes	Yes	44,768	12.0	0.0	49.8	960.9	6,640	19.90	30,407.26	531,231.63
Cumberland Regional Health Care Centre	Northern	Regional	Yes	Yes	15,443	8.8	2.2	37.4	271.7	4,409	742.02	17,956.72	136,672.23
Dartmouth General Hospital	Central	Regional	Yes	Yes	108,035	7.0	0.2	22.0	1,199.9	4,629	143.01	25,434.72	791,595.04

Figure 7.4 Population-Weighted Distance

7.4 Dashboard

The tool also features a dashboard that will update to display the changes to the system that are caused by changes to the user inputs. There is a table that shows summary statistics for the overall system as seen in Figure 7.5. The values in the DA Covered by # of EDs within *S* km field are dependent on the value of *S* (the designated distance in kilometres which the user is interested in) that the user sets at the top of the tool.

	ED Catchment Population	DA to ED Distance (km)	DA Covered by # of EDs within *S* km
Mean	24,912	12.77	4.27
Median	14,023	7.86	4
Min	1,348	0.02	1
Max	159,724	71.42	7
Variance		153.32	2.10
Standard Deviation		12.38	1.45
Mode			4
Total	921,727	20,820.69	6,965

Figure 7.5 Summary Statistics

Another display that is impacted by the user-chosen value of *S* is the table and graph shown in Figure 7.6. This table will show the population covered within *S* km of an ED, and the population that is not covered.

Population within *S* km of at least one ED

Within *S* km of at least 1 ED	% of Population	Population
Covered	100.0%	921,727
Not Covered	0.0%	-

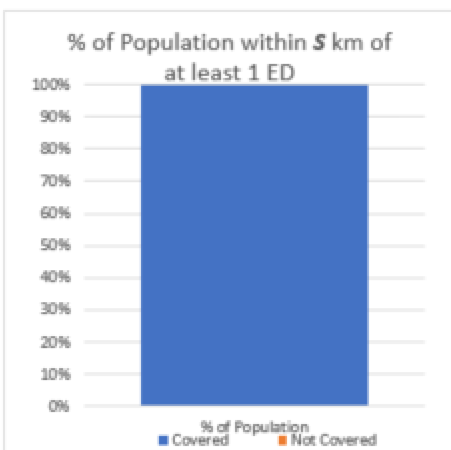

Figure 7.6 Display - Population within S km of at least one ED

Another part of the dashboard summarizes how much of the population is within the same user-specified *S* km of *n* (0, 1, 2, etc.) EDs. For example, in Figure 7.7, 4% of the total population (37,567 people) are within *S* km (in this case *S* = 72 km) of 1 ED. These same results are displayed in the table and the graph.

Population within *S* km of n EDs

n	% of Population	Population
0	0%	-
1	4%	37,567
2	6%	56,218
3	16%	148,972
4	25%	229,819
5	18%	165,307
6	28%	260,299
7	3%	23,545
8	0%	-
9	0%	-
10	0%	-
>10	0%	-
Total	**100%**	**921,727**

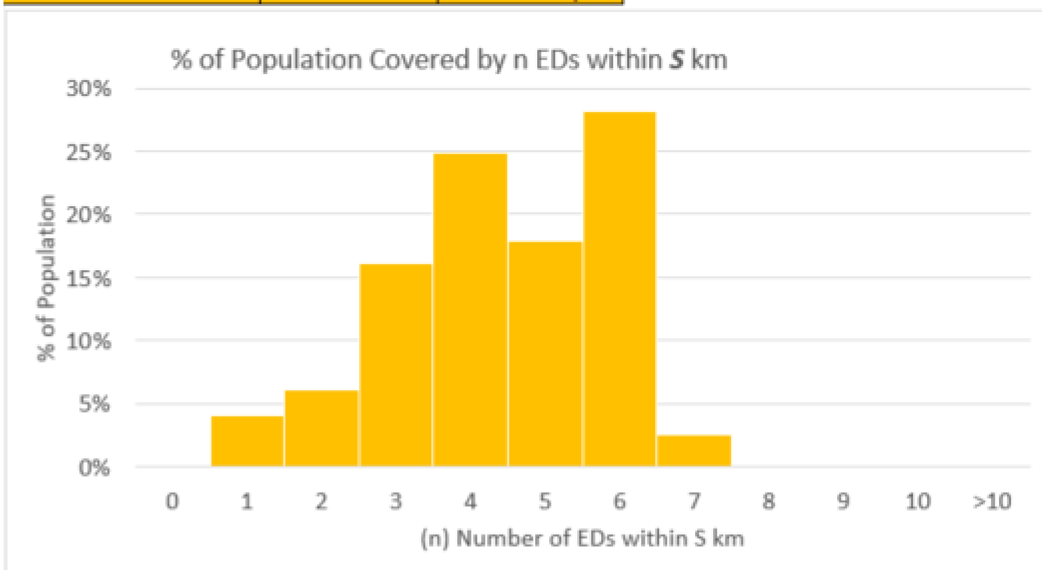

Figure 7.7 Display - Population within S km of n EDs

The final dashboard display indicates the population that is within *x* km (*x*=10, 20, etc.) of an ED. For example, Figure 7.8 show that 60% of the total population is within 10 km of an ED, and the 19% of the population is within 20 km of an ED.

Population within x km of an ED

x (km)	% of Population	Covered Population
10	60%	555,793
20	19%	173,085
30	11%	97,191
40	6%	55,367
50	3%	28,897
60	1%	8,588
70	0%	2,010
80	0%	796
90	0%	-
100	0%	-
>100	0%	-
	100%	921,727

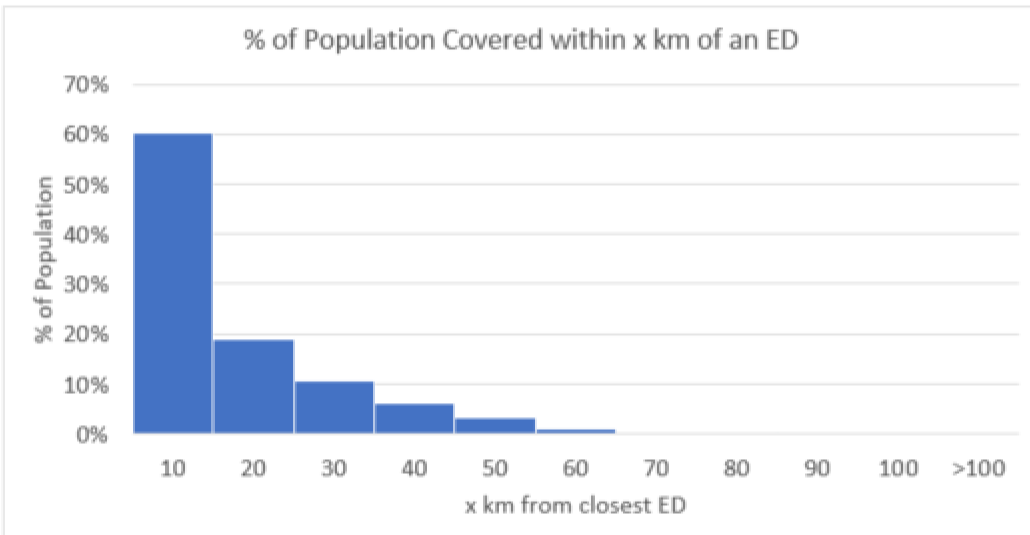

Figure 7.8 Display - Population within x km of an ED

7.5 Changes to Current State

The tool allows the user to make changes to the original state to see what happens to the overall system. The changes include closing EDs, closing EDs at night, closing CECs, and opening new EDs. These changes will be applied and the dashboard and other metrics will be updated to reflect the changes.

The user can close EDs using a drop-down menu, as seen in Figure 7.9, to see what happens to the system when the ED is closed and its population is reassigned to other EDs.

ED	Zone	ED Type	ED Open	ED Open (Night)
Aberdeen Hospital	Northern	Regional	No	Yes
All Saints Springhill Hospital	Northern	CEC	Yes	Yes
Annapolis Community Health Centre	Western	CEC	Yes	Yes
Buchanan Memorial Community Health Centre	Eastern	Community	Yes / No	Yes
Cape Breton Regional Hospital	Eastern	Regional	Yes	Yes
Cobequid Community Health Centre	Central	Community	Yes	No
Colchester East Hants Health Centre	Northern	Regional	Yes	Yes
Cumberland Regional Health Care Centre	Northern	Regional	Yes	Yes

Figure 7.9 Close EDs

The user can set which EDs are closed at night using a drop-down menu as seen in Figure 7.10. They are then able to press a button to calculate the state of the system based on the scheduled nighttime closures which will update the results throughout the dashboard.

ED	Zone	ED Type	ED Open	ED Open (Night)	ED Catchment Population
Aberdeen Hospital	Northern	Regional	Yes	Yes	45,643
All Saints Springhill Hospital	Northern	CEC	Yes	Yes	7,643
Annapolis Community Health Centre	Western	CEC	Yes	Yes	6,454
Buchanan Memorial Community Health Centre	Eastern	Community	Yes	Yes	2,769
Cape Breton Regional Hospital	Eastern	Regional	Yes	Yes	72,576
Cobequid Community Health Centre	Central	Community	No	No	
Colchester East Hants Health Centre	Northern	Regional	Yes	Yes / No	57,137
Cumberland Regional Health Care Centre	Northern	Regional	Yes	Yes	15,443
Dartmouth General Hospital	Central	Regional	Yes	Yes	127,339
Digby General Hospital	Western	Community	Yes	Yes	15,089
Eastern Memorial Hospital	Eastern	Community	Yes	Yes	1,348
Eastern Shore Memorial Hospital	Central	Community	Yes	Yes	3,478
Fishermen's Memorial Hospital	Western	Community	No	No	
Glace Bay Health Care Facility	Eastern	Community	Yes	Yes	30,009

Figure 7.10 Close EDs - Nighttime

Each of the EDs has a field indicating the type of ED. The user can press a button to calculate the state of the system if all the CECs are closed which will update the results throughout the dashboard.

The user can also add EDs to the system. Each of the DA points is listed as a candidate location for an ED. The user can use the DA glossary to look up a location where they would like to add an ED to the system. They can choose the new ED location based on a county that they are interested in, and then choose a DA point based on its geographic location within the county. They can then open an ED at that site in the tool site and evaluate the overall system with the new EDs included

An electronic companion including the Tool and Video Tutorials is available from the author.

Chapter 8 Conclusion

This chapter discusses the results and learnings developed in this thesis. It also explores the limitations of the data and methods, and identifies areas for future research.

8.1 Discussion

This research developed a method for measuring changes to the Emergency Care Network in Nova Scotia. It objectively measures what happens to the local areas as well as the system when changes to the system are made. It demonstrates that geographic information systems are a valuable tool for manipulating geospatial data.

This thesis shows that population can be used as a substitute for patient data when considering the location of EDs. The representation of the population using Statistics Canada Dissemination Area centroids is a way to use standard, available data. The use of this standardized data will also permit the model to be updated as new censuses are released.

This study uses location-allocation models such as the p-median problem, the p-centre problem, and the MCLP in atypical ways. These established location-allocation models are used as the framework for measuring the current system, as well as measuring changes. As the locations of the EDs are typically fixed, the adaptation of the models for allocation instead of determining ED locations provides a quantitative measure of the proximity between EDs and the population they serve.

Using the p-median problem the population-weighted distance of the existing system is measured. It can be concluded that 48% of the population in NS is within 0-5,000 population-weighted km of an ED, meaning that larger populations are close to EDs or that smaller populations are further from EDs.

The p-centre problem was used to measure the worst-served DA populations assigned to each ED. New Waterford Consolidated has the shortest maximum

DA to ED distance at 9.38 km and Buchanan Memorial Community Health Centre has the worst maximum DA to ED distance at 71.42 km.

The MCLP indicates that Nova Scotia's population is well covered by EDs. It shows that 60% of the population is within 10 km of an ED and that 99% of the population is covered within 60 km. It also shows that all Nova Scotians are covered by at least one ED within 72 km and that most of the province is redundantly covered by two or more EDs within 72 km.

The greenfield analyses indicate that the existing ED locations are close to the optimal locations determined by the model. The greenfield analyses show that the current number of EDs could be relocated in some areas to better serve the population and decrease the population-weighted distance of the system but that in general the EDs are located near to the higher population density areas.

The CEC analyses show that of the six sites identified as possible future sites, St. Anne's Community and Nursing and Eastern Memorial Hospital fit best within the existing CEC sites based on catchment population and distance. St. Mary's Memorial Hospital and Victoria County Memorial Hospital have similar assigned populations but are more isolated. Northside General Hospital and Fisherman's Memorial Hospital are close to other system supports but have much higher populations than the existing CECs.

Benchmarking the NS system to the PEI and NB systems shows that the population in NS must travel a shorter average distance to reach an ED. This is true even though PEI has a smaller population and a much smaller area than NS. The larger NS population is also travelling shorter distances than the NB population.

The tool that was developed will allow stakeholders to investigate the system effects and local effects of proposed changes to the system. The tool allows users to add or remove an ED, change an ED type, and change the opening hours (day versus night) of the EDs. It allows users to measure the catchment population, distance, and population-weighted distance of each ED and its population, as well as the same measures for the overall system.

8.2 Limitations

Limitations of this research include the assumptions that were made. A key assumption that was made is that population can be used as a proxy for ED demand. Another assumption assumed that the population will travel to the closest ED in an emergency.

A limitation of this study is that the capacity of the EDs is not considered when modeling the assignment of DAs using the location-allocation models. The p-median problem, p-centre problem, LSCP, and MCLP do not incorporate a facility capacity when assigning population to the EDs.

Another limitation is that the model does not permit patients to cross the provincial border from NB for service at the NS EDs near the border such as Cumberland Regional Health Care Centre in Upper Nappan. Conversely the model does not permit the assignment of NS population to NB EDs. This could be limiting the accuracy of EDs near the NS/NB border as there can be some patient crossover.

A significant portion of the Emergency Care Network relies on the ambulance and paramedic coverage of EHS which was not measured in the study. The coverage provided by EHS is particularly important in rural areas as it increases the overall system access to the Emergency Care Network. This coverage is important as the EDs and EHS are an integrated system and when one or the other is overloaded it impacts the coverage of the entire system. The EHS coverage was not measured in this study due to lack of available data.

8.3 Future Research

Future research has been proposed to build and expand on the foundation created in this research in the following ways: 1) By incorporating the province's ambulance service in addition to its EDs; 2) By incorporating additional determinants of the need for emergency services; 3) By incorporating access to emergency services; 4) By benchmarking to additional provinces; and 5) By incorporating ED Capacity into the model.

Unlike EDs, ambulance locations dynamically adjust to the system status. As a result, the response time is non-stationary, and state dependent. This requires a considerably different method for quantifying coverage than those used for EDs. Working with EHS, the current practice will be examined to characterize the nonstationary behavior and develop methods to account for it.

Population demographics and health status vary considerably from one NS region to another with the disparity most apparent when comparing rural and urban NS. As such, demand for emergency care and the type of care may vary in different areas of the province. To account for this will require demographic data for DAs (age, disease prevalence, etc.) from Statistic Canada and further research into how these factors influence emergency care demand.

In addition to the varying demographics, rural and urban NS have somewhat different challenges. In rural NS, access challenges are generally related to distance to the closest full-service ED, and the response capability of smaller EDs; ranging from being closed, to being an assess and transfer / treat node in the integrated network of emergency care. Once patients arrive at a rural ED they are generally served without considerable delay. In urban NS, EDs are generally located nearby but there is often a considerable wait for care once arriving at the ED (this is of course acuity dependent) and almost entirely driven by the boarding of in-patients in the ED. Quantifying both delays (travel to the ED and waiting in the ED) and then understanding how this may relate to health outcomes (while considering confounders) is an area for future research.

Benchmarking across provinces outside of the Maritimes is one way to further this research. There is interest in comparing Nova Scotia to both Ontario and Alberta.

Incorporating the ED capacity is another way to improve the study in the future. From a clinical standpoint, future research could include the linking of health outcomes to the EDs. This could be included in future research using information from the EDs regarding the number of beds and resources available.

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Appendix: Literature Review Summary – ED Categorization

Paper	Based on	Limited	Basic	Advanced	Comprehensive
Myers et al. (2013)	• Staffing and resources • Unique Categorization for Pediatric	Limited	Basic	Advanced	Comprehensive
Kocher et al. (2010)	• Vertical Categorization • Clinical silos/clinical conditions of a specific patient population	Limited ED and inpatient care	Basic ED and inpatient care	Advanced ED and inpatient intensive care	Comprehensive ED and specialized inpatient intensive care
		Limited diagnostic services and equipment	Select diagnostic, operative, and therapeutic services and equipment	Most specialized diagnostic, operative, and therapeutic services and equipment	Comprehensive diagnostic, operative, and therapeutic services and equipment
		Limited specialist physicians	Select specialized physicians available for consult	Promptly available specialists	In-house/promptly available specialists
		Typically transfer seriously ill and critically ill patients to higher levels of care for stabilization and post-stabilization care	Often transfer some seriously ill patients, and most critically ill patients for stabilization and post-stabilization care	Occasionally transfer patients for post-stabilization specialty care	Rarely transfer patients for post-stabilization specialty care
Kocher et al. (2010)	• Horizontal Categorization • ED capabilities • Resources available to all types of patients, including	Services for a narrow range of medical conditions	Services for a moderate range of medical conditions	Advanced services for a wide range of medical conditions	Comprehensive ED services for a full range of medical conditions
		Physicians are on-call 24/7	ED physicians on duty 24/7	24/7 coverage by emergency physicians	24/7 board-certified emergency physicians

Paper	Based on	Limited	Basic	Advanced	Comprehensive
	those who do not fit in a disease specific vertical silo	Little access to inpatient care, diagnostic, operative, and therapeutic services and equipment	Basic inpatient care as well as basic diagnostic, operative, and therapeutic services and equipment	Access to specialized inpatient intensive care and most specialized diagnostic, operative, and therapeutic services and equipment	Access to specialized inpatient intensive care and diagnostic, operative, and therapeutic services and equipment
		Limited specialist physicians available for consultation	Select specialist physicians are available on call	Specialist physicians are either promptly available or on-call	Wide range of in-house/on-call physician specialists
		Typically transfer seriously and critically ill patients to higher levels of care for stabilization and post-stabilization care	Seriously ill patients and most critically ill patients are often transferred for stabilization and post-stabilization care	Occasionally transfer critically ill patients for post-stabilization care	Rarely transfer patients for post-stabilization care
Carr et al. (2011)	• Available resources and personnel	• Physician extender or physician available from home, • A general surgeon available within	• Physician available immediately, • A general surgeon available within an hour [33].	• Attending physician immediately available • A limited array of consultants available within an hour	• Emergency physician immediately available • A broad array of consultants available within an hour • Additional consultants available outside of one hour

Paper	Based on	Limited	Basic	Advanced	Comprehensive
		an hour			
		• CT scan available but not within one hour	• CT scan within an hour	• CT scan, ICU, OR available within an hour	• a CT scan, Intensive Care Unit (ICU), Operating Room (OR), cardiac catheterization with percutaneous coronary intervention capability within an hour

Appendix: P-Median Problem Results

P-median assigned population from lowest-to-highest.

ED	ED Type	Population	% of Total Population	Sum of Distance (km)	Population-Weighted Distance
Eastern Memorial Hospital	Community	1,348	0.15%	23.00	5,645.89
Eastern Shore Memorial Hospital	Community	2,579	0.28%	129.82	66,171.15
St. Mary's Memorial Hospital	Community	2,725	0.30%	145.82	78,903.58
Buchanan Memorial Community Health Centre	Community	2,769	0.30%	171.69	83,808.35
St. Anne's Community and Nursing	Community	3,286	0.36%	47.74	26,259.23
Victoria County Memorial Hospital	Community	3,584	0.39%	140.24	63,403.41
Sacred Heart Community Health Centre	Community	3,719	0.40%	126.92	57,167.48
Guysborough Memorial Hospital	Community	3,754	0.41%	193.23	91,817.94
South Cumberland Community Care Centre	CEC	4,095	0.44%	206.29	95,472.98
North Cumberland Memorial Hospital	CEC	4,697	0.51%	186.61	86,645.02
Lillian Fraser Memorial Hospital	CEC	6,293	0.68%	256.22	121,097.22
Annapolis Community Health Centre	CEC	6,454	0.70%	211.26	97,688.68
Inverness Consolidated Memorial Hospital	Community	7,105	0.77%	357.59	174,013.15
All Saints Springhill Hospital	CEC	7,643	0.83%	161.63	66,981.59
Queens General Hospital	Community	9,181	1.00%	287.27	114,859.07
New Waterford Consolidated Hospital	CEC	10,484	1.14%	56.47	29,790.53
Musquodoboit Valley Memorial Hospital	CEC	12,991	1.41%	595.45	338,538.69
Twin Oaks Memorial Hospital	CEC	13,457	1.46%	325.35	219,535.89
Roseway Hospital	Community	14,023	1.52%	803.53	465,377.95
Strait Richmond Hospital	Community	14,547	1.58%	845.72	393,893.32
Digby General Hospital	Community	15,089	1.64%	838.51	374,827.75
Cumberland Regional Health Care Centre	Regional	15,443	1.68%	271.66	136,672.23

ED	ED Type	Population	% of Total Population	Sum of Distance (km)	Population-Weighted Distance
St. Martha's Regional Hospital	Regional	17,629	1.91%	469.58	208,146.50
Fishermen's Memorial Hospital	Community	18,072	1.96%	741.21	390,170.46
Glace Bay Health Care Facility	Community	21,205	2.30%	231.52	113,797.38
Northside General Hospital	Community	21,342	2.32%	367.91	196,761.48
Soldiers' Memorial Hospital	Community	24,284	2.63%	629.10	325,826.91
Hants Community Hospital	Community	26,052	2.83%	936.15	473,069.12
South Shore Regional Hospital	Regional	28,595	3.10%	845.03	380,138.61
Yarmouth Regional Hospital	Regional	30,476	3.31%	1,094.98	614,514.88
Aberdeen Hospital	Regional	43,355	4.70%	992.06	476,616.96
Colchester East Hants Health Centre	Regional	44,768	4.86%	960.89	531,231.63
Valley Regional Hospital	Regional	47,413	5.14%	1,119.30	565,220.72
Cape Breton Regional Hospital	Regional	50,214	5.45%	1,133.17	599,438.29
Dartmouth General Hospital	Regional	108,035	11.72%	1,199.90	791,595.04
Cobequid Community Health Centre	Community	115,297	12.51%	2,102.72	1,612,195.23
QEII - Halifax Infirmary Site	Tertiary	159,724	17.33%	1,615.14	1,043,742.33
Grand Total		**921,727**	**100.00%**	**20,820.69**	**11,511,036.62**

P-median Problem average distance from DA to ED

ED	ED Type	Population	% of Total Population	Average Distance from DA to ED (km)	Average of Population-Weighted Distance
New Waterford Consolidated Hospital	CEC	10,484	1.14%	2.69	1,418.60
Glace Bay Health Care Facility	Community	21,205	2.30%	5.51	2,709.46
QEII - Halifax Infirmary Site	Tertiary	159,724	17.33%	6.28	4,061.25
Dartmouth General Hospital	Regional	108,035	11.72%	7.02	4,629.21
Eastern Memorial Hospital	Community	1,348	0.15%	7.67	1,881.96
St. Anne's Community and Nursing	Community	3,286	0.36%	7.96	4,376.54
Cumberland Regional Health Care Centre	Regional	15,443	1.68%	8.76	4,408.78
All Saints Springhill Hospital	CEC	7,643	0.83%	8.98	3,721.20
Northside General Hospital	Community	21,342	2.32%	9.43	5,045.17
Aberdeen Hospital	Regional	43,355	4.70%	11.15	5,355.25
Cape Breton Regional Hospital	Regional	50,214	5.45%	11.56	6,116.72
Colchester East Hants Health Centre	Regional	44,768	4.86%	12.01	6,640.40
Valley Regional Hospital	Regional	47,413	5.14%	12.44	6,280.23
St. Martha's Regional Hospital	Regional	17,629	1.91%	13.04	5,781.85
Soldiers' Memorial Hospital	Community	24,284	2.63%	13.68	7,083.19
Cobequid Community Health Centre	Community	115,297	12.51%	13.74	10,537.22
Queens General Hospital	Community	9,181	1.00%	14.36	5,742.95
South Shore Regional Hospital	Regional	28,595	3.10%	14.83	6,669.10
Annapolis Community Health Centre	CEC	6,454	0.70%	15.09	6,977.76
Sacred Heart Community Health Centre	Community	3,719	0.40%	15.86	7,145.93
Twin Oaks Memorial Hospital	CEC	13,457	1.46%	16.27	10,976.79
Victoria County Memorial Hospital	Community	3,584	0.39%	17.53	7,925.43
Eastern Shore Memorial Hospital	Community	2,579	0.28%	18.55	9,453.02

ED	ED Type	Population	% of Total Population	Average Distance from DA to ED (km)	Average of Population-Weighted Distance
North Cumberland Memorial Hospital	CEC	4,697	0.51%	18.66	8,664.50
Yarmouth Regional Hospital	Regional	30,476	3.31%	19.55	10,973.48
Lillian Fraser Memorial Hospital	CEC	6,293	0.68%	19.71	9,315.17
Hants Community Hospital	Community	26,052	2.83%	20.35	10,284.11
Fishermen's Memorial Hospital	Community	18,072	1.96%	21.18	11,147.73
South Cumberland Community Care Centre	CEC	4,095	0.44%	22.92	10,608.11
Inverness Consolidated Memorial Hospital	Community	7,105	0.77%	23.84	11,600.88
Guysborough Memorial Hospital	Community	3,754	0.41%	24.15	11,477.24
Digby General Hospital	Community	15,089	1.64%	25.41	11,358.42
Musquodoboit Valley Memorial Hospital	CEC	12,991	1.41%	25.89	14,719.07
Strait Richmond Hospital	Community	14,547	1.58%	27.28	12,706.24
Buchanan Memorial Community Health Centre	Community	2,769	0.30%	28.61	13,968.06
St. Mary's Memorial Hospital	Community	2,725	0.30%	29.16	15,780.72
Roseway Hospital	Community	14,023	1.52%	30.90	17,899.15
Grand Total		**921,727**	**100.00%**	**12.77**	**7,061.99**

Appendix: Tool

An electronic companion including the Tool and Video Tutorials is available via DalSpace.